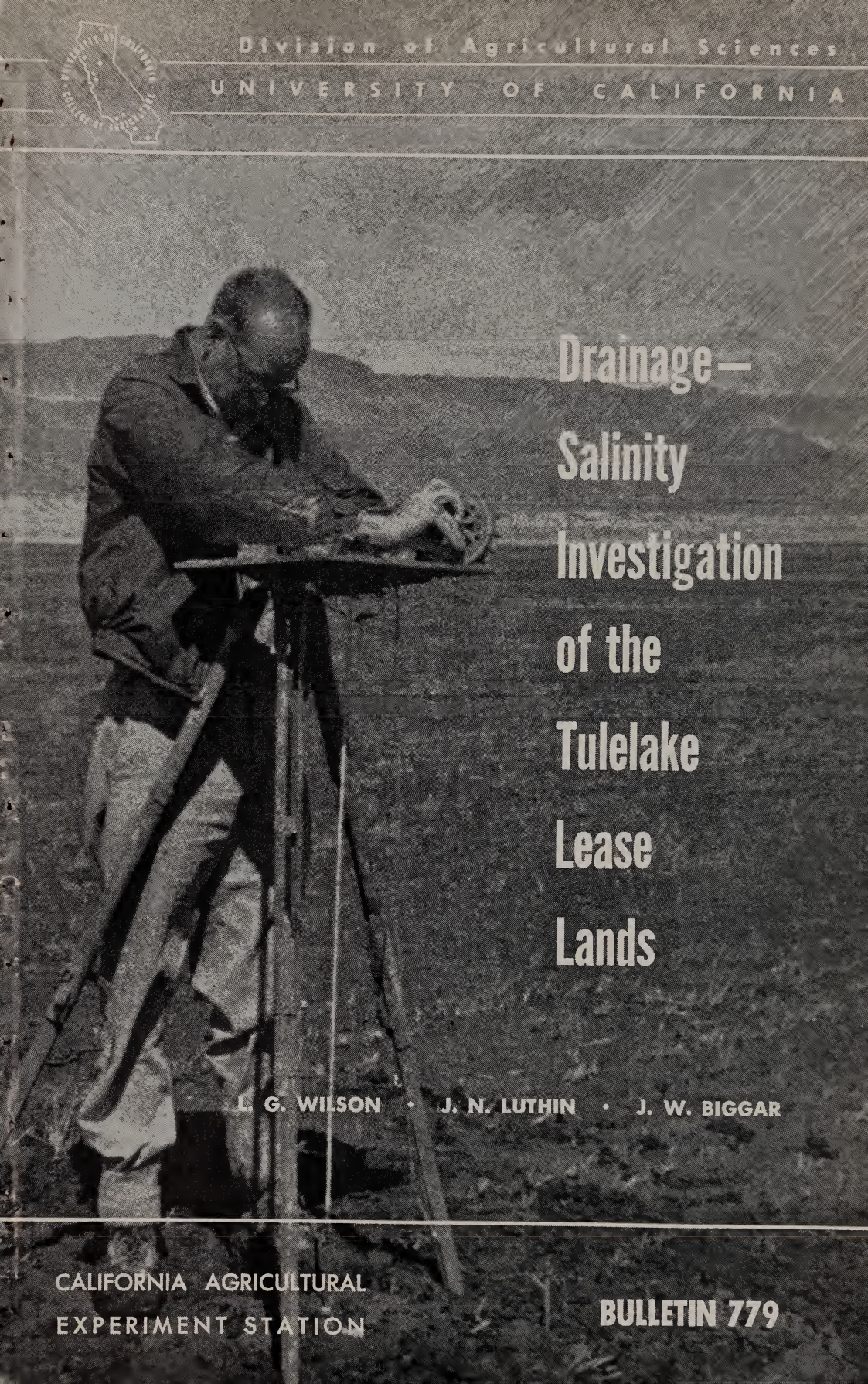




Division of Agricultural Sciences
UNIVERSITY OF CALIFORNIA

A black and white photograph of a man in a field, wearing a jacket and glasses, leaning over a tripod-mounted instrument, likely a surveying level or theodolite. The background shows a flat, open landscape under a clear sky.

Drainage— Salinity Investigation of the Tulelake Lease Lands

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CALIFORNIA AGRICULTURAL
EXPERIMENT STATION

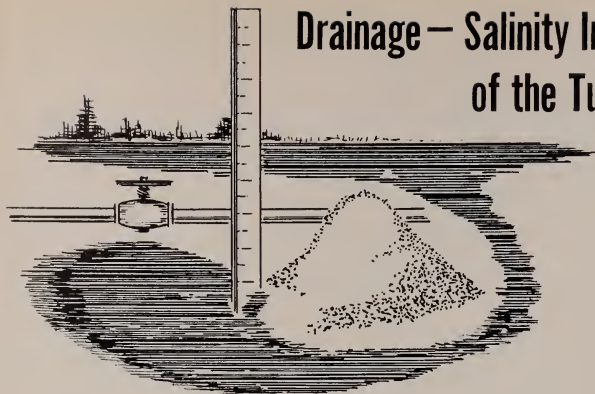
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CONTENTS

Introduction	6
Water Supply Features of the Klamath Project	6
Geology of the Tulelake Basin	8
Soils and Soil Charac- teristics	10
Drainage-Salinity Investigations, 1955 and 1956	17
Drainage Investigation	17
Salinity Investigation	18
Results	23
Effect of Drains on Salinity	26
Relationship Between Salinity and Water Table Levels	29
Discussion	30
Conclusions	31
Study of Deep and Shallow Open Drains, 1957	31
Construction Problems	31
Effect of Deep Drains on Water Tables	33
Shallow Drains	34
Conclusions	34
Drainage-Salinity Investigation, 1958	35
Drainage Investigation	35
Procedures and Materials	35
Results	37
Discussion	41
Salinity Investigation	43
Procedures	43
Results	46
Literature Cited	56

APRIL, 1961

Drainage—Salinity Investigation of the Tulelake Lease Lands¹



THIS BULLETIN REPORTS the results of four years of studies in the Tulelake lease lands after farmers of that area noticed a build-up of salinity in their fields causing an appreciable decline of their potato and grain yields. The problem was brought to the attention of the Irrigation Department of the University of California by the Tulelake Farm Advisor. An initial survey indicated a correlation between a severe salinity problem and the levels of the water tables. It was tentatively concluded that the build-up of salinity in the soils was caused by evaporation from the shallow water table prevalent throughout the lease lands, and that present drainage systems were inefficient in controlling water table levels.

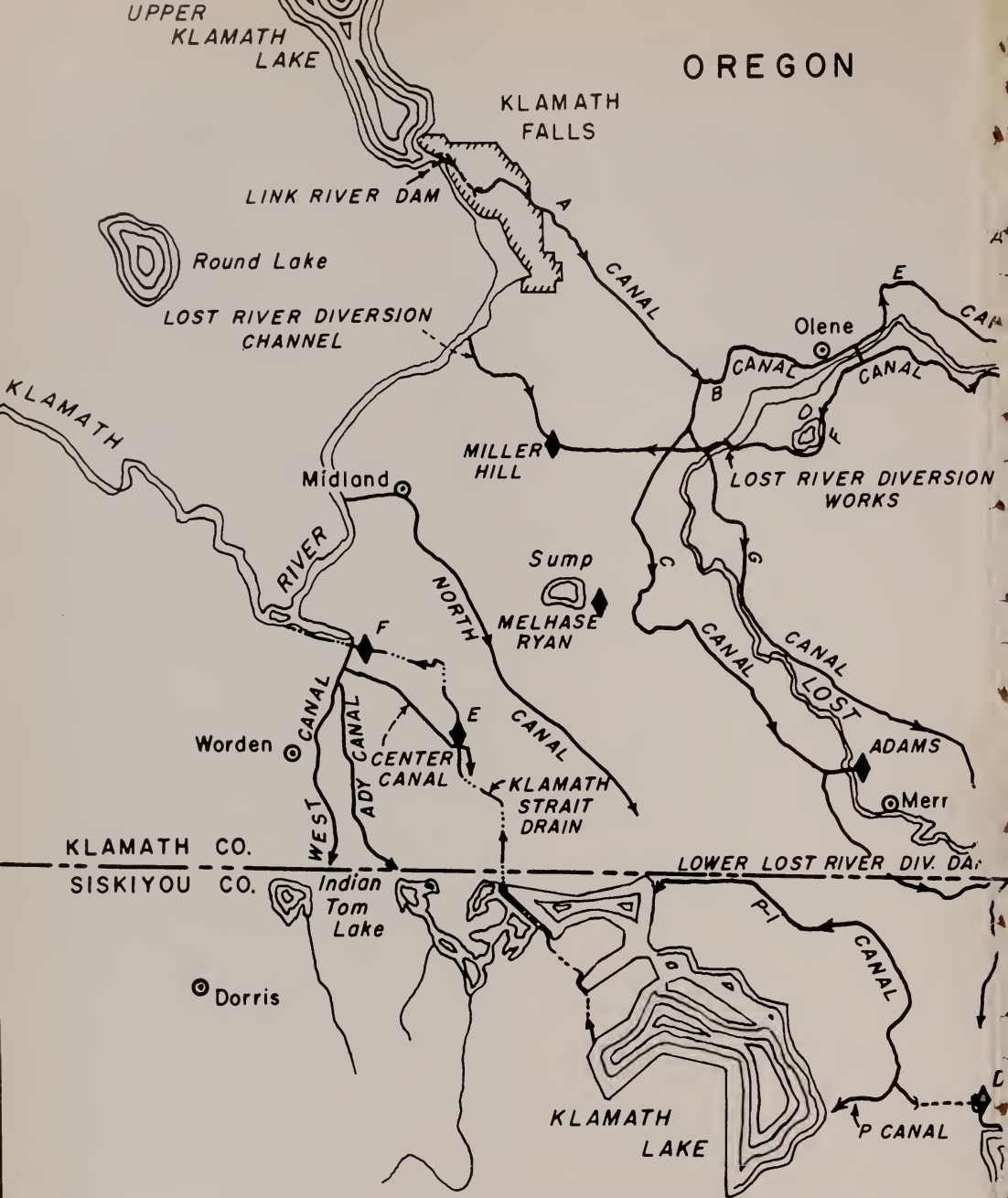
To determine the extent of the problem and find possible remedies, the U. S. Bureau of Reclamation agreed to conduct a joint investigation with the University of California. The studies began in 1954 with preliminary work, and continued through the summer of 1958 when a detailed experiment was conducted on a 78-acre tract of public land.

This bulletin summarizes the objectives, procedures, and conclusions reached during each year of the investigation.

¹ Submitted for publication, June 16, 1960.

THE AUTHORS

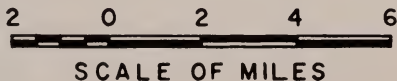
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U.S.B.R.
KLAMATH PROJECT

EXPLANATION

- ◆ PUMPING PLANT
- L.N. LEAGUE OF NATIONS
- F.P. FROG POND
- S.W.S. SOUTHWEST SUMP



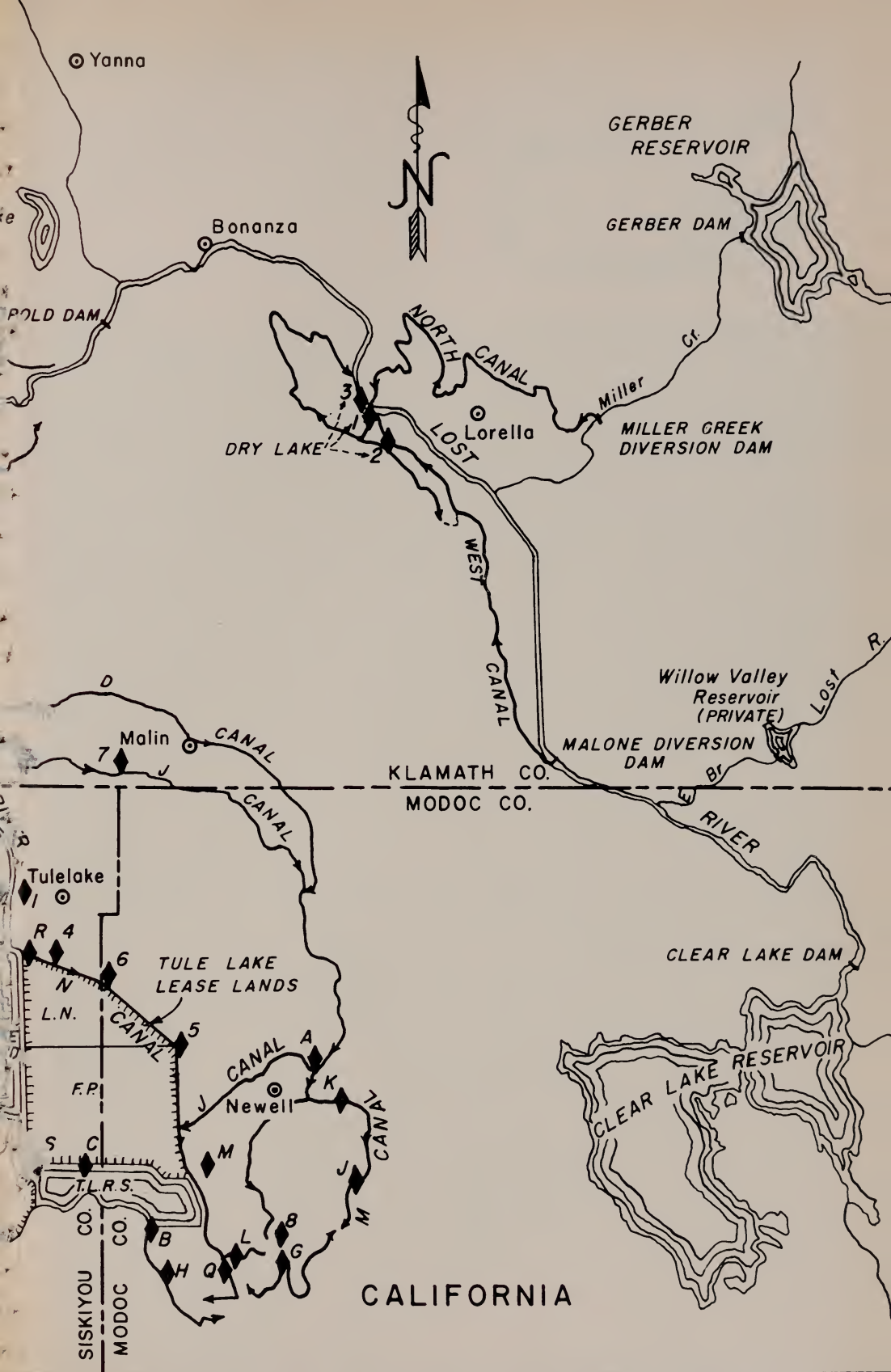
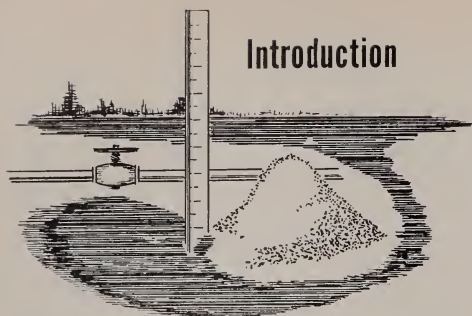


Figure 1



Water Supply Features of the Klamath Project

The Tulalake Basin, being naturally enclosed, became submerged to the extent of some 96,000 acres before drainage from the Lost River Basin (1,620 square miles) was brought under control. Because of its agricultural potential, the Federal Reclamation Service (now the Bureau of Reclamation) in 1905 began to divert water from the basin to permit reclamation, and constructed irrigation and drainage structures to facilitate agricultural development after reclamation. The Tulalake Basin, and land in Oregon affected by flooding of the Klamath River, were organized into the Klamath Federal Reclamation Project. Construction was started in 1906 and the first water delivered May 16, 1907. In 1906 a homestead program was started, and the first water delivered to these lands in 1909. Upon drainage and reclamation of Tulalake, additional homestead openings have increased the irrigated area; also some public lands have been reclaimed and farmed on a lease basis. Altogether, it is estimated (U. S. Department of Interior, 1957a) that, including private and public land in the Klamath Project, irrigation service is provided to about 200,000 acres.

The total watershed area contributing to the Klamath Project contains about 9,500 square miles, the majority of which lies in Modoc and Siskiyou counties, California, and Klamath County, Oregon. The two major water sources for the

project are the Upper Klamath Lake and Klamath River, and Clear Lake which, in conjunction with Tulalake and connecting Lost River, forms a closed basin. The largest of these sources is Upper Klamath Lake which forms a reservoir behind the Link River Dam of capacity 766,000 acre feet. The Klamath River is fed by this lake and by diversions from Lost River which, in turn, is mainly supplied by Clear Lake Reservoir and Gerber Reservoir.

The water control structures of the project include three dams (see figure 1). The Link River Dam is located on the Link River, at the head of the Klamath River, and regulates the flow from Upper Klamath Lake Reservoir. The dam is of reinforced concrete slab-type structure, height 22 feet and crest length 435 feet. Gerber Dam, located on Miller Creek, a tributary of the Lost River, is a concrete arch-type structure, height 88 feet and crest length 485 feet. The reservoir capacity is 94,300 acre feet. A portion of the flow into Tulalake is reduced by this structure. Clear Lake Dam and Reservoir, located at the head of the Lost River, provides storage for irrigation and also reduces flow into Tulalake. This is an earth and rock-filled dam, height 39 feet and crest length 840 feet.

Four diversion dams are included in the project: Malone Diversion Dam on Lost River and Miller Creek Diversion Dam on Miller Creek divert water to serve land in Langell Valley. Lost River Diversion Dam controls downstream flow on the Lost River and consequently prevents expansion of Tulalake by diverting excess water to the Klamath River through the Lost River Diversion Channel. This channel serves not only to convey excess water during peak flows of Lost River to the Klamath River, but also flow can be reversed during periods of low flow in the Lost River, and Klamath River water provided to compensate for irrigation deficiencies. The lower Lost River Diversion Dam diverts water from

Lost River to provide an irrigation supply for the land reclaimed from Tulelake bed, including the Tulelake lease lands.

Twenty-eight pumping plants are included in the project with power input varying from 15 to 3,650 hp, lifts ranging from 4 to 67 feet, and capacities of

from 3 to 300 cfs. There are 13 canals totaling 120 miles in length with diversion capacities of from 100 to 300 cfs. Laterals total 463 miles and drains 340 miles.

The major portion of the Tulelake Division of the Klamath Project consists

Main pumping plant D. Drainage water is lifted to the tunnel located directly above and behind the pumping plant. It then flows by gravity through the mountains to the lower Klamath Lake.



of three parts containing a total of 62,280 irrigable acres. Parts 1 and 2 contain 44,081 irrigable acres, and part 3, consisting of the Tulalake lease lands and Southwest Sump, contain 18,199 irrigable acres. The bulk of the water is obtained from the Lost River at the Lost River Diversion Dam and delivered through the J Canal. Pumping plants 1 to 6 inclusive are drainage pumps which deliver return flow water from land in Tulalake Division part 1 into the restricted sump or into N Canal for use on the lease lands. The drainage water pumped into the N Canal is diluted with water from the restricted sump. Pumping plants S and C pump drainage water from the Tulalake lease lands into the interconnected restricted sump. Pumping plant D, in turn, delivers water from the restricted sump through a 6,600 ft. concrete lined tunnel (250 cfs capacity) to Lower Klamath Lake. Additional pumps lift the water from Lower Klamath Lake back into the Klamath River, completing the circuit.

Prior to 1957 the operation and maintenance of irrigation and drainage works of the Tulalake Division were under the jurisdiction of the Bureau of Reclamation. In January 1957, the dikes, distribution and drainage systems of this division were transferred to the newly formed Tulalake Irrigation District.

Geology of the Tulalake Basin

The Tulalake Basin is located on the Modoc Plateau, the California portion of the Columbia Plateau, a volcanic field occupying a high semiarid area between the Warner Mountains and the Cascade Range, and encompassing a vast area in Washington, Oregon, and southern Idaho. Because of the geologic and historic interest of the Modoc Plateau, an area of about 75 square miles has been set aside as the Lava Beds National Monument.

The geology of this area has not been investigated extensively, although the salient features have been discussed by Peacock (1931), and Hinds (1952). Peacock considers the main characteristics of the region to be little moded plateau surface, mountains of volcanic accumulation, and mountainous and hilly regions whose configuration was caused by dislocation and erosion. "In the Modoc area the Trans-Cascade Plateau has a general elevation of about 3,500 feet. Rising to a maximum height of 3,500 feet above this level are a number of wide mountainous and hilly areas, and entrenched to a depth of more than 2,500 feet below the general plateau surface, the Pit River marks the lowest level in the region."

The oldest feature in the Modoc Lava Field are tilted tuff and trap hills in the south, southeast, and north, probably developed during early Tertiary times. They form wide tracts of height varying from 500 to 1,500 feet above the general plateau. The ridge dominating the west side of Tulalake is of this nature. The rocks composing these hills are the oldest in the region and consist of "a series of dense dark basalts of exclusive and inclusive character, massive accumulation of basic, intermediate, and acidic tuffs and breccias, minor bodies of intrusive acidic rocks, and water-laid sediments of various kinds, the relative proportions of these components varying from place to place" (Peacock). The original formations were probably continuous, and because the present hills and highlands are detached, the action of erosion and/or fracturing of the original formation followed by differential subsidence of dislocated blocks is indicated. Peacock and Hinds consider that the first phase of vulcanism in the Modoc Plateau was explosive and related to central vents about which volcanoes developed. Volcanic activity probably was intermittent and during the quiescent periods lacustrine and other sediments were laid down,

only to be covered by subsequent outbursts of the same cycle.

A second type of highland called the Shasta Lava Highlands, as defined by Peacock, consists of a broad, irregular, mountainous belt occupying the mid-western and southwestern parts of the region extending east to the Central Volcanic Dome. This area merges, to the west, with the base of Mt. Shasta. The material of the highland differs from that of the older formation and consists of "a massive, deeply dissected series of gray, loose textured lavas, mainly andesites and basalts with some subordinate obsidians, very different from the dense, dark traps occurring in the older formation. The massive gray lavas were apparently delivered from central volcanoes of the Shasta type." The relief developed during this period of time is the greatest in the area with several mountains over 6,000 feet and with the Pit River cutting the formation below the 2,000 foot level. The main factor developing the present configuration appears to be erosion in conjunction with initial irregularities. The Shasta lavas follow the general rule that basic igneous material weathers more readily than acid igneous material and have given rise to abundant gray soils that support heavy timber growth.

The third and youngest type of highland in the area is called the Modoc Plateau, which occupies more than one-half of the whole sheet and whose elevations vary consistently between 4,500 and 5,000 feet. Most of the plateau was constructed during Pleistocene time, although evidence is available (from dead trees, for example) that the youngest flows were deposited only a few centuries ago. Peacock divides the lavas of the plateau into three groups based on age, mode of eruption, and respective influence on appearance of the plateau surface. The three groups are described by Hinds as follows:

... the oldest (are) by far the thickest and most extensive. These lavas were

apparently highly liquid, forming thin, rather even surfaced flows, were erupted from fissures rather than from central openings, and flooded the region to build up a plain of gently undulating surface. The second group is comprised of generally much rougher surfaced flows, mostly erupted from central vents about which were constructed broad, low shield volcanoes. Explosive eruptions also occurred forming a considerable number of small cinder cones.

The third group includes the most recent flows such as the Callahan on the northern edge of the Medicine Lake Highland, an eastward-projecting promontory of the Cascade Range and the Burnt Lava at the southern margin of the same area. The flow surfaces are chaotic jumbles of great blocks. Rising from their surfaces are cinder cones whose craters and outer slopes are almost perfectly preserved, testifying to the recency of the activity; in fact, this suggests the definite possibility of further eruptions...

Several lakes in past and recent geologic times have deposited lacustrine materials on the lava flows. The major recent lakes are Medicine Lake, Clear Lake, Klamath and Lower Klamath lakes, and Tulelake. (Tulelake has dried up in recent time and similar shrinkage has occurred in Lower Klamath Lake).

Peacock summarizes the events bearing on the origin and history of Tulelake as follows:

Towards the end of the volcanic period in which the older lavas originated, probably towards the close of the Miocene, the country was traversed by a series of fractures trending north and south in accordance with the main trend of the Basin Range faulting. Irregular differential subsidence of the dislocated blocks produced horst and graben structure and initiated vigorous degradation. The Modoc Plateau lavas were then poured out on the comparatively level sedimentary plains lying between the horsts, and renewed crustal movements along the north-south fractures produced the horst and graben structure of the plateau... Again erosion and sedimentation were promoted, and the wide areas of lake sediments... were deposited.

The present Tulelake sediments lie on the lavas of the Modoc Plateau, indicating that this lake formed after the formation of the plateau, and according to Peacock in late Pleistocene or recent time. Lacustrine sediments visible under the older lavas of the plateau on the east side of the Tulelake Basin also indicate that more extensive lakes existed before Modoc lavas were deposited. In fact, because of the geologic construction of the area it is possible to uncover old lake sediments at great depths below the present soil surface. This is indicated by examination of the two well logs given in tables 1 and 2.

When Tulelake was initially surveyed in 1884 it occupied an area of 150 square miles. Surveyed again in 1924, it occupied an area of only half this size. Today the lake bed is entirely dry. The control of the inflow of water by project structures to Tulelake and the construction of pumping plant D has permitted the reduction of the former Tulelake to the present open water sumps. An unpublished study of the so-called underground passages, made many years ago by the Bureau of Reclamation, showed that the amount of water removed through these passages was small. About 36 inches of water a year is the average evaporation in the Tulelake area.

Soils and Soil Characteristics

To date there has been only one detailed soil survey (U. S. Department of Agriculture, 1908) conducted in the Tulelake area; at the time of this survey the lake was still quite extensive so that the data are valueless for modern interpretation. The Bureau of Reclamation has conducted a land classification survey (U. S. Bureau of Reclamation, 1950), but its major purpose was to investigate the lands for irrigation feasibility. Dachnowski-Stokes (1936) made a reconnaissance survey of the lake bed and gives

the only detailed profile available in the literature. This profile was obtained in the NW $\frac{1}{4}$ Sec. 5, T. 47N, R4E and showed the following characteristics:

0 to 12 inches, sedimentary muck. The upper 9 inches of the cultivated organic soil consist of dark-gray mellow diatomaceous material which is loamy in character. Below this is a brownish-gray diatomaceous organic sediment containing a few flattened root stocks of water lily, rhizomes, and rootlets of tule in an advanced stage of decomposition, and possibly an admixture of clay. The underlying material is a thin band of white pumice which resembles coarse sand.

12 to 36 inches, very compact greenish-brown or olive-green organic sediments, largely diatomaceous and more or less banded.

36 to 72 inches, gray siliceous predominantly diatomaceous sediments. This material includes thin bands of coarse pumice from volcanic eruptions and varying quantities of clayey residue brought in, probably, by flood waters.

The material grades rather abruptly into a light-gray accumulation of siliceous remains of diatoms which was not probed below a depth of 8 feet from the present surface.

The most significant feature of the soils of Tulelake, as observed in this profile, is the high amount of diatomaceous earth they contain. This material, briefly described here, is responsible for many of the unusual characteristics of these soils.

Diatomaceous earth is composed of the remains of countless numbers of one-celled organisms called diatoms. Taxonomically, diatoms belong to the Phylum Chrysophycophyta class of Bacillarieae, one of the seven phyla of algae. It has been estimated (Leppla, 1953) that there are about 10,000 varieties of diatoms. Diatom cells contain a nucleus, vacuoles, cytoplasm and golden-brown chromoplasts. Chlorophyll a and c, fucoxanthin and carotenoids are present, rendering the diatoms autotrophic. The cell wall is composed of silica-impregnated pectin

and consists of two halves fitting together much like the two parts of a petrie dish. During reproduction by cell division the two halves separate, each daughter cell receiving one-half of the old cell wall. The daughter cells then build a new second half of the cell wall fitting inside the original half (Robbins and Weier, 1950).

Under proper environmental conditions cell division is quite rapid and it has been calculated that one frustule would become a billion diatoms within a month, if the time of a single subdivision were 24 hours (Leppla, 1953). Deposits of diatomaceous earth are formed by settling of the large masses of dead diatoms on the bed of the lake in which they have lived.

Diatomaceous earth chemically consists mainly of silica and has been described as deposits of opaline silica in a classification of the minerals of California (Murdock and Webb, 1956). There are no known published analyses of diatomite from the Tulelake area, but an analysis has been determined for samples from Klamath Lake and will probably serve to approximate Tulelake deposits. The analysis is given in table 3.

TABLE 3
ANALYSIS OF DIATOMITE 4.5 MILES
SOUTHWEST OF KLAMATH FALLS
(MOORE, 1937)

Chemical	Per cent
SiO ₂	75.56
TiO ₂	0.64
Fe ₂ O ₃	2.66
Al ₂ O ₃	8.64
CaO	1.20
MgO	0.37
Na ₂ O	1.08
K ₂ O	0.26
SO ₃	0.06
Cl	None
CO ₂	0.11

The remainder is water and organic matter.

The source of silica apparently is the volcanic deposits common in areas where diatomaceous earth develops (Taliaferro,

TABLE 1
WELL LOG DRILLING, AUGUST 1950
WELL LOG NO. 3, CITY OF TULELAKE

Material	Depth (ft.)	Thickness (ft.)
Mud.....	170	170
Pumice.....	171.5	1.5
Mud.....	185	13.5
Pumice.....	186	1
Mud.....	190	4
Pumice.....	191	1
Mud.....	247	56
Sand black.....	247.5	0.5
Mud.....	283	35.5
Peat brown.....	290	7
Sand black.....	291.5	1.5
Mud.....	593	301.5
Chalk.....	603	10
Mud.....	850	247

TABLE 2
WELL LOG DRILLING, NOVEMBER 1953
WELL LOG NO. 4, CITY OF TULELAKE

Material	Depth (ft.)
Lake bottom mud.....	0 (Ground level)-150
Lake bottom mud.....	150- 283
Pumice and shells.....	283- 291
Lake bottom mud.....	291- 825
Mud, shale streaks, and sand.....	825-1105
Shale.....	1105-1255
Hard sand.....	1255-1259
Mud.....	1259-1325
Hard shale.....	1325-1336
Soft shale.....	1336-1567
Sand streaks and shale.....	1567-1597
Shale.....	1597-1610
Rock.....	1610-1673
Clay and shale.....	1673-1679
Rock abrasive.....	1679-1725
Lava rock hard.....	1725-1865
Shale tough.....	1865-1870
Rock.....	1870-1917
Shale tough.....	1917-1922
Green shale and sand streaks.....	1922-1981
Soft lava rock and clay streaks.....	1981-2129
Soft clay.....	2129-2172
Rock-sand streaks.....	2172-2200
Rock.....	2200-2207
Lava rock soft.....	2207-2248
Lava rock.....	2248-2391
Lava rock, lime deposits.....	2391-2444
Soft lava rock.....	2444-2454
Broken lava rock.....	2454-2480
Hard rock.....	2480-2503
Sandy lava rock.....	2503-2548
Soft lava rock, shale streaks.....	2548-2566
Firm lava rock.....	2566-2582
Firm rock.....	2582-2600
Firm rock.....	2600-2607
Lava cinders.....	2607-2665
Hard black rock.....	2665-2676

1935). These deposits create large amounts of hydrous silicates and silicic acid in the water in which the organisms live.

The most outstanding characteristic of diatomaceous earth, and which makes this material industrially important, is its low bulk density. Some values for Oregon deposits are given in table 4.

TABLE 4
APPARENT DENSITY OF DRIED
SAMPLES OF DIATOMITE
(MOORE, 1937)

District	Apparent density (lbs/ft ³)
Torrebonne	21.8
"	28.7
Harper	27.1
"	33.8
"	26.7
"	29.2
Austin	29.1
Otis Basin	33.8
"	30.1
"	26.6
Klamath	34.6
"	32.1

Soil texture. One of the characteristics of the Tullake soils which make them useful for field research is their uniformity of texture throughout large areas. Data from the mechanical analysis of a typical profile is given in table 5.

This analysis shows the predominance of clay- and silt-sized particles through-

out the profile. The composition of this material is, of course, largely diatomaceous earth. The large amount of sand at the 66-inch depth is probably pumice material. In addition, it is not uncommon to find large quantities of fresh-water shells in these soils. Because of the large amount of organic material in the surface of these soils, not shown in the analysis, they would probably be best classified as organic clay loams, or more specifically, peaty or mucky clay loam depending on the degree of decomposition of the organic material. In addition to the volcanic origin of the soils, some material was brought in by the Lost River.

Soil structure (the groupings of primary soil particles into aggregated units separated from adjacent units by surfaces of weakness) has two important effects on soil as a medium for plant growth. First, structure determines to a great extent the ability of the soil to transmit water. Secondly, as a corollary to the first, structure contributes to aeration of the soil.

Tullake soil structure was probably formed in the following manner: At the beginning, when the area was submerged, the dead remains of countless numbers of diatoms slowly settled to the bottom of the lake, forming the typical horizontal laminar structure of lacustrine deposits. Over a vast period of time a considerable depth of diatomaceous soil material was

TABLE 5
MECHANICAL ANALYSIS OF TULELAKE SAMPLES*

Depth	Sand	Silt	Clay	Fine clay	Texture
inches	per cent				
0-12	26.5	43.2	25.4	4.9	Clay loam
12-18	17.0	35.3	40.2	7.5	Clay
18-24	15.5	31.9	43.3	9.3	Clay
24-30	16.2	41.0	35.7	7.1	Silty clay
30-42	18.1	39.1	35.3	7.5	Clay
42-48	16.0	46.8	30.9	6.3	Silty clay loam
48-54	36.0	32.4	26.8	4.8	Clay loam
66+	54.5†	18.3	23.0	4.2	Sandy clay loam

* Sand 0.05-2.00 mm; Silt 0.002-0.05 mm; Coarse clay 0.2-2.0 microns; Fine clay 0.2 microns. Determined at Ohio State University.

† Variation in sand ±13.



Exposed diatomaceous soil in bottom of shallow drainage ditch.
Note the large cracks due to drying.

deposited along with pumice material derived from the volcanic outbursts. As mentioned previously, volcanic material served as the source of silica used in the cell walls of the diatoms.

When the water in the lake became sufficiently shallow to permit plant growth, the peat deposits of the area began to be developed. Their shallow depths indicate that the time of peat formation was very short compared to the time of the formation of the diatomaceous deposits.

As the water began to disappear from the surface of the former lake, the soil material was probably essentially structureless except for the laminar nature of the deposits. When the water table began to recede even further as a result of natural or man-made drainage, the action of alternate wetting and drying began to develop vertical cracks in the soil.

Over the period of time that these soils have been drained and cultivated, a fairly

definite structure has been built up which may best be described as prismatic. The cracks play an important role in drainage because they increase the permeability. Although no data are available, it appears from observations of water flow into newly opened ditches, that a large proportion of the water flow occurs through these cracks.

The structure of Tulelake soils appears susceptible to deterioration through compaction. For example, one road constantly used by heavy equipment was found to be compacted to such an extent that it formed a dam preventing drainage from an adjacent field into an open ditch on the other side of the road.

Porosity. The high macroporosity of Tulelake soils, to which the structural cracks contribute, is based on the intrinsic nature of the material itself. The pore space can be determined from bulk-density-particle-density calculation—or

TABLE 6
MOISTURE EQUIVALENT (ME) AND 15 ATMOSPHERE DATA FOR
TULELAKE SOILS*

Depth (in.)	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
	ME (per cent)	15 atm. (per cent by wt.)	ME (per cent)	15 atm. (per cent by wt.)	ME (per cent)	15 atm. (per cent by wt.)	ME (per cent)	15 atm. (per cent by wt.)	ME (per cent)	15 atm. (per cent by wt.)
0-12.....	67.89	55.04	66.43	52.47	70.69	56.49	66.96	53.51	64.56	47.85
12-24.....	84.39		84.30		86.96		87.54		89.71	
24-36.....	83.80		80.80		78.50		85.44		88.32	
36-48.....	75.33	51.41	76.78	48.54	78.48	52.79	77.27	47.61	79.48	50.25
48-60.....	75.48		79.35		91.67		76.50		76.84	
60-72.....	71.90		73.73							
Average.....	76.46		76.90		81.26		78.74		79.78	

* Determined by Irrigation Department, University of California, Davis.

can be estimated from per cent by volume water held at saturation. Such values obtained by the latter approach are given in table 8, where the per cent by volume held at saturation ranged from 71.41 per cent to 76.68 per cent with an average of 74.85 per cent. These values are approximately in the 75 to 88 per cent range given by Leppla (1953) for porosity of diatomaceous earth. Values for the water-holding capacity of this soil at saturation, expressed on a per cent by weight basis, are also given in table 8. These values range from 140.27 to 172.0 per cent by weight with an average of 154.6 per cent for the entire profile. This compares to values normally obtained for organic soils rather than those for mineral soils.

Field capacity, as defined by Veihmeyer and Hendrickson (1948), is "the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased." This soil property is obtained in the laboratory by two techniques, the moisture equivalent method or the one-third atmosphere percentage method. The moisture equivalent is obtained by centrifuging saturated soils in perforated cups at a rate equivalent to a force of 1,000 times gravity for 30 minutes. The one-third atmosphere percentage is obtained by bringing the soil moisture in a

sieved and saturated soil sample into equilibrium at one-third atmosphere. These two values have been found to correlate closely with each other. They are generally lower than field capacity in coarse soils, equal to field capacity at moisture values at 20 per cent, and higher than field capacity in fine textured soils.

Moisture equivalent and one-third atmosphere percentage values for a number of Tulelake samples are given in tables 6 and 7. The one-third atmosphere values are slightly higher than those for moisture equivalent and range from 81.05 to 107.12 per cent with an average

TABLE 7
MOISTURE EQUIVALENT DATA FOR
TULELAKE*

Sample No.	Soil	
	Depth (inches)	ME (per cent)
2-D.....	0-10	69.4
	10-30	84.8
	30-60	73.8
11-D.....	0-12	70.0
	12-30	77.1
	30-60	80.6
10-E.....	0-12	67.8
	12-30	75.2
Average.....		74.84

* Determined by U.S.B.R.

TABLE 8
TULELAKE SOIL SAMPLES—PHYSICAL DATA*

Sample No.	Depth (inches)	H ₂ O at satur. (per cent by wt.)	H ₂ O at satur. (per cent by vol.)	H ₂ O at 1/3atmos. (per cent by wt.)	H ₂ O at 1/3atmos. (per cent by vol.)	15 atmos. (per cent by wt.)	15 atmos. (per cent by vol.)	Dp† (gm/cm ³)	Dp† (lbs/ft ³)
1.....	0-12	140.27	71.41	81.05	41.26	51.12	26.02	2.259	153.34
2.....	12-18	152.90	76.24	97.32	48.50	62.81	31.28	2.398	149.54
3.....	18-24	157.03	75.16	91.51	43.80	69.35	33.22	2.449	152.72
4.....	24-30	162.80	76.68	103.23	48.63	65.22	30.72	2.441	152.22
5.....	30-42	172.04	76.56	101.28	45.07	66.45	29.57	2.445	152.47
6.....	42-48	122.10	72.56	79.51	47.29	55.56	33.00	2.482	154.78
7.....	48-54	157.79	75.22	97.87	46.66	71.81	34.53	2.414	150.54
8.....	66+	171.61	74.97	107.12	46.78	62.62	27.36	2.312	144.18
Average.....		154.6	74.85	94.86	46.00	63.12	30.71	2.425	151.22

* Determined at Ohio State University.

† Particle density.

of 94.86 per cent. Moisture equivalent values for all samples range from 64.56 per cent to 91.67 per cent with an average of 78.00 per cent. The data point out that the field capacity in the first foot of soil is lower than elsewhere in the soil. This seems paradoxical because of the high organic content of the surface which should raise the moisture equivalent above the deeper soils.

The high values of moisture equivalent for these soils are even more pronounced when compared to values for mineral soils; clays are about 30 per cent, loams about 20 per cent, and sand 8 to 10 per cent. In fact, the moisture equivalents of Tulelake soils are comparable to those for organic soils rather than mineral soils. Feustel and Byers (1936), for example, report values for moss peat, sedge peat, and reed peat of 166, 112, and 100 per cent respectively.

The lower limit of the so-called "available moisture range" is represented in this report by the 15-atmosphere percentage. The technique consists of determining the amount of water retained in a previously saturated soil sample which has been placed on a porous membrane and which has been permitted to come to equilibrium with 15-atmosphere pressure in the gas phase.

Fifteen-atmosphere percentage values for Tulelake soils are given in tables 6

and 8. The range of values in these tables is from 47.61 to 71.81 per cent by weight. The average value for the profile given in table 8 is 63.12 per cent. These values are more comparable to those obtained for organic soils than for mineral soils. Typical values for mineral soils are: clay 15 per cent, loam 10 per cent, and sand 4 per cent. The three organic materials tested by Feustel and Byers (1936), moss peat, sedge peat, and reed peat had wilting percentages of 82.3, 60.8, and 70.7 respectively.

The moisture characteristics of the diatomaceous soils of Tulelake may be summarized by saying that the saturation percentage, field capacity, and 15-atmosphere percentage values are considerably higher than values expected for typical mineral soils and compare closely to values for organic soils.

Permeability or hydraulic conductivity of a soil is an important characteristic because it gives an idea of the ease with which drainage can occur. It may be defined as the rate of water transmission through a porous medium under a given potential gradient. Permeability can be determined in the field in a number of ways but the two most common are the auger hole and piezometer techniques (Luthin, 1957). Briefly, the auger hole technique consists of augering a hole into the soil below the water table. The

water in the hole is pumped out and the rate of rise of water table determined. Knowing the shape of the hole together with the depth to water before pumping and rate of rise of water, a curve may be used to determine permeability in inches per hour. The piezometer technique uses a pipe driven into the ground below the water table with the soil augered out of the pipe. A cavity is augered below the end of the pipe and water pumped out of the pipe. The rate of rise of water in the pipe together with the geometry of the cavity can be used to determine permeability from a chart or by calculation. The auger hole technique gives an average permeability throughout the depth that the water table is lowered. The piezometer method, on the other hand, gives the soil permeability directly at the end of the pipe.

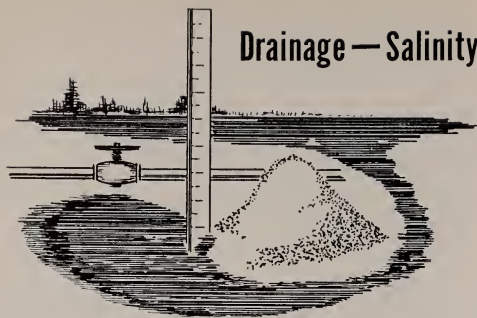
Because of the high permeability of the surface 5 feet of Tulelake soils it is difficult to determine permeability by these methods. The hole fills so rapidly after pumping that one does not always

have time to lower a measuring device into the hole. Successful tests gave permeability values of 7 to 14 inches per hour.

The permeability of the material below about 5 feet (that is, below the zone of drying and shrinking; best described as diatomaceous ooze) is extremely different from that of the surface. For example, measurements of permeability at 6 feet and deeper by the piezometer method gave values of about 0.001 inch per hour. The vast permeability differences between surface and subsurface soils appears to be caused mainly by the difference in structure. The surface soil, in which alternate wetting and drying, freezing and thawing, and root action have contributed to formation of a pronounced structure, contains a large number of cracks which are able to transmit water rapidly. Below the depth of these activities the soil is essentially structureless and, in spite of the large microporosity of the material, water transmission is very slow.

Measuring the soil hydraulic conductivity by the auger hole method.





Drainage—Salinity Investigations, 1955 and 1956

The objectives of the 1955 and 1956 investigations were fundamentally the same and consisted of two phases:

Drainage Investigation

To determine water table levels throughout the lease lands.

To study the efficiency of present drainage methods in controlling water table levels.

To determine sources of excess water creating drainage problems and factors limiting efficiency of present drainage techniques.

Salinity Investigation

To determine salinity levels throughout the lease lands and delineate specifically affected areas.

To determine the nature of the saline soils.

To determine relationship between salinity and depth to water table.

To examine specific areas to determine relationship between salinity and drain spacing.

To determine relationship between salinity and crop yields.

Drainage Investigation

To determine the depths to water throughout the lease lands, 31 observation wells were installed during the spring of 1955. Nine of these wells were installed in the League of Nations, 15 in the Frog Pond, and seven in the Southwest Sump. These wells consisted of standard pipe in about 5-foot lengths

driven into the ground and augered out. They were read bimonthly during the summers of 1955 and 1956.

In addition to these observation wells, 10 Stevens Type F automatic stage recorders were installed in 1955 to give a better picture of water table fluctuations than can be obtained from observation wells. Four of the automatic recorders were re-installed in 1956. These instruments made it possible to obtain an estimate of the efficiency of drains in controlling water levels.

Average depths to water table for the summers of 1955 and 1956, in the three areas of the lease lands studied are given in table 9.

TABLE 9

AVERAGE DEPTHS TO WATER TABLE
IN THE TULELAKE LEASE LANDS
1955-1956 (FT.)

Area	1955	1956
League of Nations	2.92	1.62
Frog Pond	2.92	2.29
Southwest Sump	2.84	1.83

Average depth to water table values are only approximately valid for such large areas and serve only as a rough estimate of actual conditions because of the limited number of observations, and also because of the possibility that some of the observation wells may not have been operating effectively.

Two primary factors contribute to the maintenance of high water table conditions in the leases. The first factor, limiting efficient control of water table levels,

is the lack of adequate drainage. The present drains in the lease land are of inadequate depth and of insufficient capacity to maintain the water table at satisfactory levels. Not only are the drains of inadequate depth, but the common practice of blocking the drain to obtain some benefit from subirrigation is detrimental to the entire area since it removes the drain from operation. The inadequate drainage in the area is evident from the graphs of the automatic recorder which show that after an irrigation the rate of drop of the water table is very slow. A contributing factor to the low capacity of the drains in the lease land is the great amount of algae found in the drain ditches. The Bureau of Reclamation and the present operators, the Tululake Irrigation District, have spent a considerable amount of money and time to control the algae, but present chemicals and eradication techniques appear to be ineffective.

The second factor, which is unfortunately common to most irrigated areas, is low irrigation efficiency. Responsible for this are the high infiltration rates of the soil necessitating large flows, and the excessive application of water in those areas where it is cheap and plentiful.

The primary reason for the higher water table levels in 1956 compared to 1955 was the above-normal amount of rainfall during the early part of 1956, shown in table 10. The 21-year average mean precipitation for the Tululake weather station was 9.97 inches per year. Precipitation from July 1955 to June 1956 was 16.67 inches compared to 5.02 inches for a similar period for 1954 to 1955.

Salinity Investigation

The presence of salt in the soil in quantities above allowable tolerances manifests itself to the farmer mainly by the reduction of crop yields. Excess salt in the soil solution influences crop growth in two ways. First, the osmotic



Water stage recorder used to measure fluctuations of the water table.

pressure is increased and this, in turn, increases soil moisture stress—which is the sum of the soil moisture tension and osmotic pressure of the soil solution. Increasing the soil moisture stress limits the water available for growth, and the plant wilts at a higher moisture content than if the osmotic component were negligible. The second factor influencing crop growth is known as the specific ion effect. This implies that specific ions produce toxic effects when taken up in other than tolerable quantities. It was not the objective of this study to determine whether osmotic pressure or toxicity effects were causing growth depression. Growth is depressed as salts accumulate in the soil, and there are wide differences in the tolerance of species to various ions.

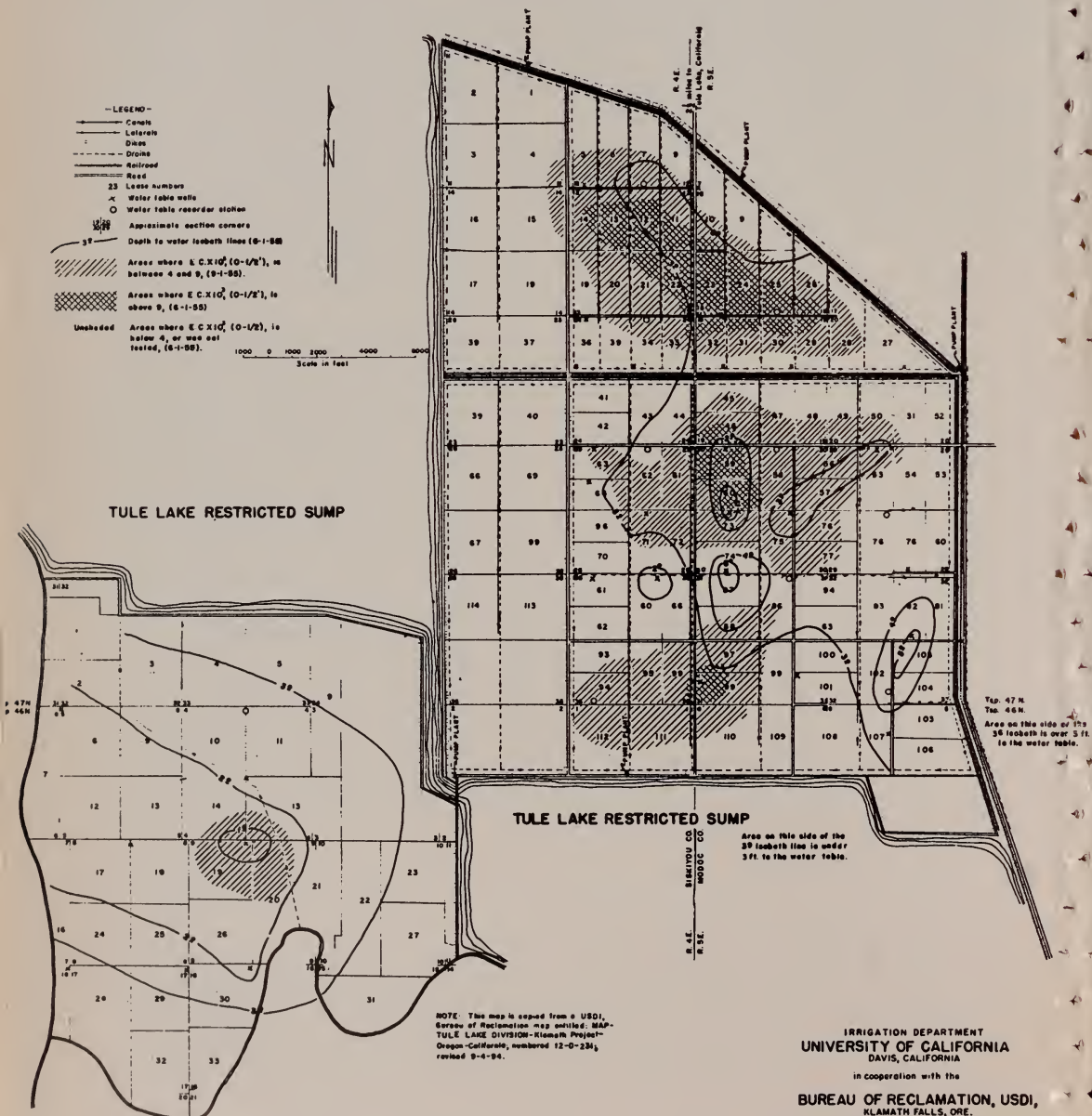
The salt content of soils can be evaluated by determining the electrical conductivity of the solution extracted from a saturated soil paste (Richards, 1954). The conductivity and the osmotic pres-

sure of a solution are both dependent upon the number of ions in solution and the concentration of the solution. An increase in the concentration of salts in solution results in an increase in the electrical conductivity and osmotic pressure of the solution. The relationship between concentrations and conductivity varies somewhat, depending on the type of salts in solution. It is possible to determine the relationships between these

two quantities for any given combination of salts. This relationship has been determined from a large number of samples taken in the Tululake area and is presented in figure 5.

Determinations of the conductivity of the saturated extract provide a means of appraising soil salinity in relation to plant growth because the saturation percentage can be directly related to the field moisture range. It has been found

Figure 2.

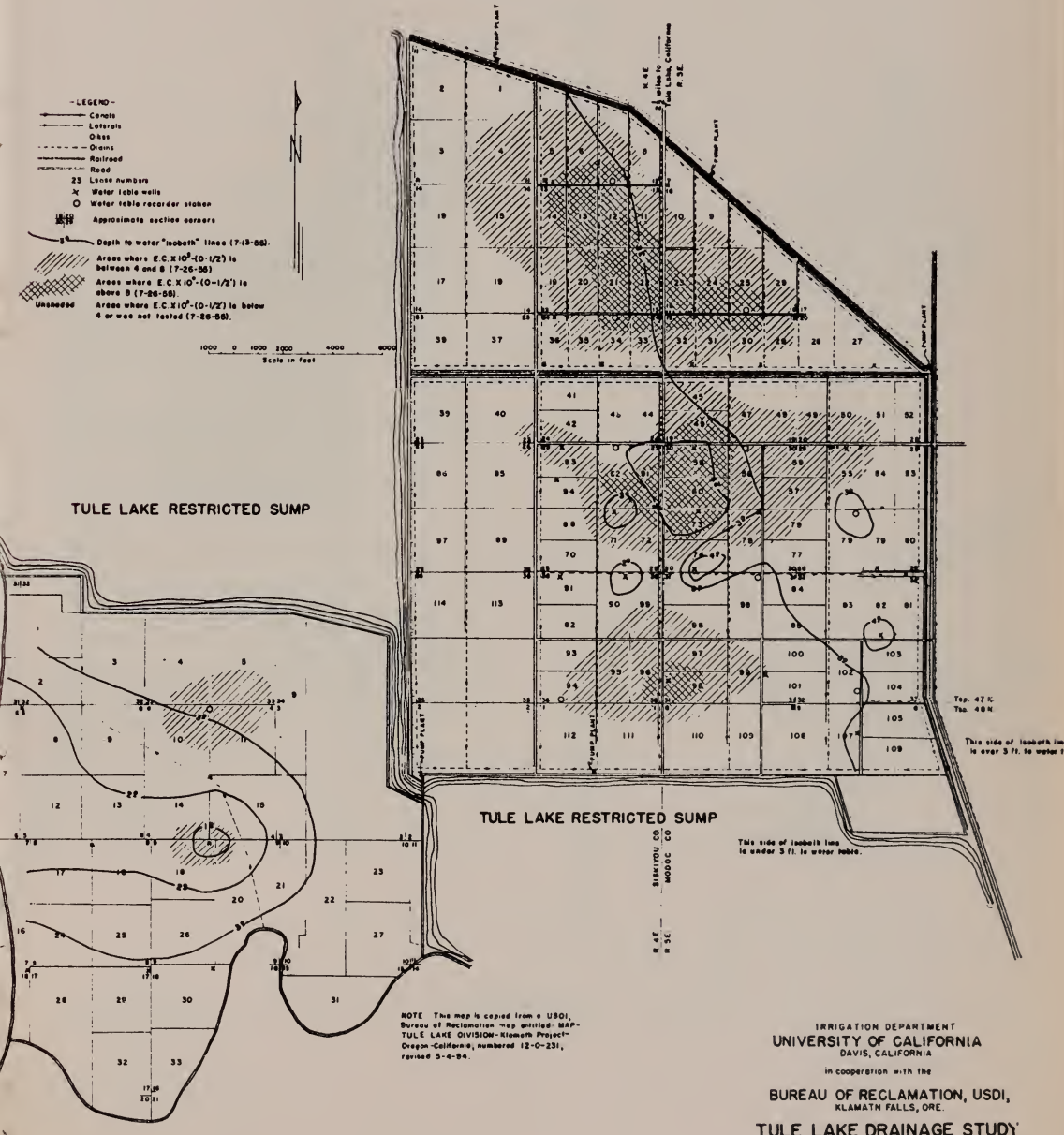


for a large number of mineral soils that the saturation percentage is about twice the value for field capacity and about four times the value for the 15-atmosphere percentage. Peats and diatomaceous soils do not necessarily follow this relationship. For example, on the basis of the analysis in table 8, the $\frac{1}{3}$ -atmosphere percentage is about 60 per cent and the 15-atmosphere percentage about 40 per cent of the saturation extract. This

means that the soil solution is 1.67 times more concentrated at field capacity and 2.5 times more concentrated at PWP, than for the saturated soil.

On the basis of studies (Richards, 1954) on the response of plant growth in the presence of soluble salts in many soils it has been possible to obtain a guide, presented in table 11, which relates the conductivity of the saturation extract to the yields of crops which may

Figure 3.



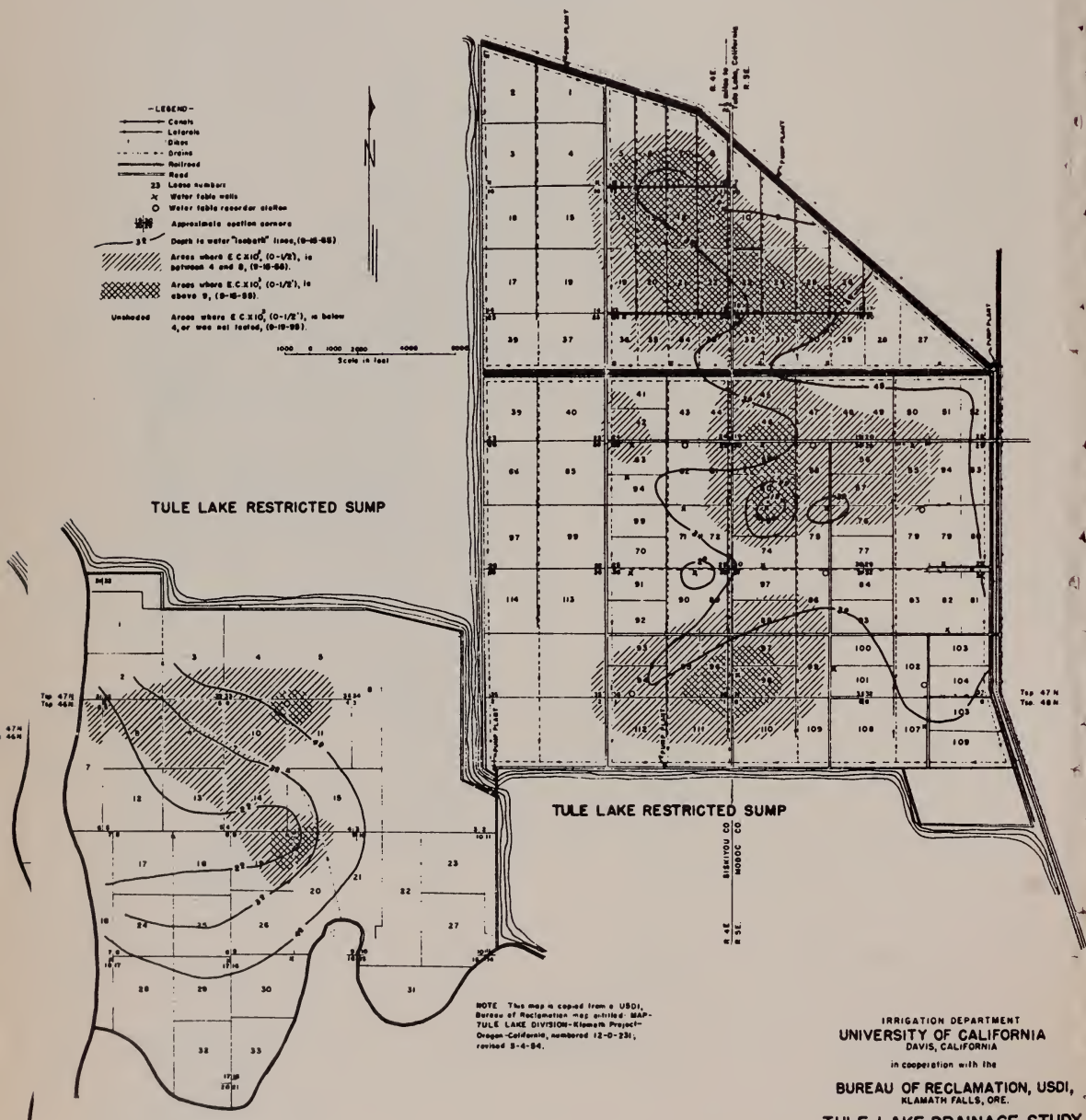
be expected when grown at the indicated levels of salinity.

The table indicates that above 4 mmhos per cm, the yield of many crops may be restricted. Soils which have a conductivity above 4 mmhos are often referred to as saline soils.

The presence of excess exchangeable sodium in the soil often-times leads to problems of water and root penetration. Exchangeable sodium percentage (E.S.

P.) is defined as the degree of saturation of the soil base exchange complex with sodium, expressed on a percentage basis. The E.S.P. of a soil which occurs when equilibrium between the soil solution and the exchange complex is reached has been estimated from the concentration of ions in the soil solution using the sodium adsorption ratio (S.A.R.). For many soils the correlation between E.S.P. and S.A.R. is good. For others it is not

Figure 4.



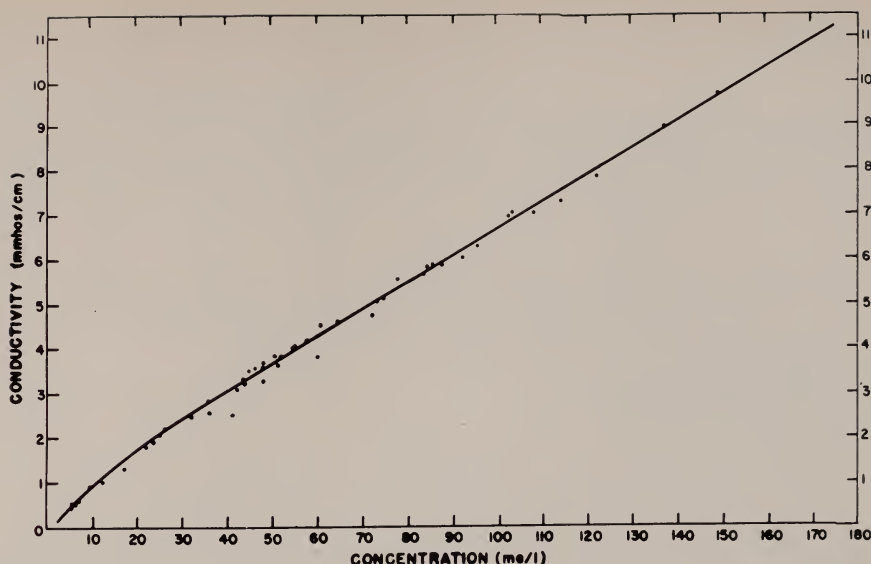


Figure 5. Concentration of saturated soil extracts (me/l) related to electrical conductivity (mmhos/cm) for Tulelake, California.

satisfactory. Although the S.A.R. has been used in the present report for estimating the E.S.P., further investigation is needed to determine the accuracy of such a procedure. The sodium adsorption ratio is defined as $Na^+ / [(Ca^{++} + Mg^{++}) / 2]^{1/2}$ where Na, Ca, Mg refer to the concentrations of the designated cations expressed in milliequivalents per liter.

Soil samples were taken in the vicinity of each observation well and automatic recorder in one-half foot increments down to three feet, three times during the summer of 1956, to estimate changes in salinity throughout each season. In addition detailed studies were conducted on specific areas to determine the relationship between the action of drains and salt concentration. An investigation of the effect of salinity on yields and vegeta-

tive growth of crops grown in the Tulelake lease lands was also conducted. Finally, the over-all relationship between salinity and water table levels was determined.

Irrigation water. Although the bulk of the irrigation water is obtained from the Lost River diversion through the J Canal, considerable mixing takes place in the areas under investigation with other waters, mainly drainage waters. Not only do these vary from place to place, but also during the season and from year to year. For this reason it is difficult to give analyses which would indicate the situation for the entire area. A few analyses are given in table 12 to indicate what has been found.

Results

Average conductivity values of satu-

TABLE 11
SCALE OF CONDUCTIVITY (MILLIMHOS PER CM AT 25°C)

Salinity effects mostly negligible	Yields of very sensitive crops may be restricted	Yields of many crops may be restricted	Only tolerant crops yield satisfactorily	Only a few very tolerant crops yield satisfactorily
0	2	4	8	16

TABLE 12
ANALYSIS OF SOME IRRIGATION AND DRAINAGE WATERS IN THE
TULELAKE AREA

Water sample No.	EC $\times 10^3$ mmhos/cm	milliequivalents per liter					
		Ca	Mg	Na	HCO ₃	Cl	SO ₄
1.....	0.35	0.78	1.26	1.37	2.28	0.28	0.96
2.....	0.42	1.00	1.20	1.60	2.00	0.30	1.10
3.....	0.52	1.28	1.88	2.39	4.11	0.34	1.17
4.....	0.89	2.60	2.92	4.14	5.37	0.45	3.91
5.....	1.46	5.68	4.56	6.61	6.45	0.96	9.48

Sample description:

No. 1—J Canal, 6/28/56
No. 2—J Canal, 9/4/54 U.S.B.R.
No. 3—Pumping Plant 5, 9/21/58
No. 4—Pumping Plant C, 7/27/56
No. 5—Pumping Plant C, 9/8/58

TABLE 13
CATION ANALYSIS OF SAMPLES TAKEN 5/25/55*

Soil depth (ft.)	EC $\times 10^3$	milliequivalents per liter					Per cent Na	ESP†
		Na	Ca	Mg	K	Total		
Lease No. 25								
0-½.....	9.74	85.22	28.50	32.65	2.87	149.24	57.2	18
½-1.....	7.86	62.61	26.60	31.65	1.28	122.14	51.3	14
1-1½.....	7.30	54.78	27.50	30.49	1.28	114.05	48.0	11
1½-2.....	6.98	48.26	26.60	27.15	0.87	102.88	47.0	10
2-2½.....	5.85	36.96	26.60	21.32	0.87	85.75	43.0	9
2½-3.....	5.25	32.61	25.00	19.58	1.02	78.21	41.5	9
Lease No. 36 (south end)								
0-½.....	3.29	17.52	14.25	10.67	2.92	45.36	38.6	5
½-1.....	4.15	24.13	18.15	14.17	1.23	57.68	41.5	7
1-1½.....	3.72	22.26	16.70	12.08	0.64	51.68	43.0	6
1½-2.....	2.48	15.50	9.58	6.50	0.51	32.09	48.2	6
2-2½.....	2.75	15.50	11.80	8.16	0.51	35.97	43.0	5
2½-3.....	2.91	15.50	13.80	8.79	0.51	38.60	40.0	5
Lease No. 78								
0-½.....	1.54	7.79	5.90	6.10	0.67	20.46	38.0	6
½-1.....	1.56	8.00	5.70	5.83	0.49	20.02	40.0	4
1-1½.....	1.07	7.30	2.85	2.71	0.37	13.23	55.3	5
1½-2.....	1.49	8.70	5.14	3.86	0.41	18.11	48.0	4
2-2½.....	1.19	5.98	4.36	2.60	0.34	13.28	45.0	4
2½-3.....	1.18	5.23	5.14	3.06	0.34	13.77	38.0	3
Lease No. 98								
0-½.....	8.98	75.65	27.50	31.65	2.46	137.26	55.0	15.5
½-1.....	7.05	50.78	26.60	24.16	1.69	103.23	49.2	11
1-1½.....	6.28	40.00	25.70	19.32	1.69	86.71	46.2	9.5
1½-2.....	5.62	35.65	23.60	17.00	1.43	77.68	45.8	9.5
2-2½.....	5.93	35.91	25.70	16.16	1.28	79.05	45.3	9
2½-3.....	6.18	38.96	25.70	16.16	1.28	82.10	47.4	10
Lease No. 15 (SW sump)								
0-½.....	2.25	14.24	7.88	6.50	1.02	29.64	48.2	6
½-1.....	2.11	13.04	6.68	5.83	0.82	26.37	49.5	5
1-1½.....	1.99	12.52	6.88	5.00	0.82	25.22	49.7	5
1½-2.....	3.56	15.39	15.75	10.67	1.23	43.04	35.7	4.5
2-2½.....	1.88	11.39	6.10	4.26	0.67	22.42	50.8	6
2½-3.....	1.56	9.65	4.56	2.76	0.67	17.64	54.5	4.5

* Obtained from saturated extracts.

† Estimated from figure 27, Agricultural Handbook 60 (Richards, 1954).

rated extracts from samples obtained in 1955 and 1956 are given in table 14. Cation analyses of the chemical constituents in the saturated extracts of five representative samples are given in table 13. In addition, the profiles of salinity obtained from three areas known to be

badly affected are shown in table 15. Monthly conductivity values for the summer of 1955 are shown in figures 2, 3, and 4.

Using the criterion that 4 mmhos conductivity of saturated extract marks the division between saline and nonsaline

TABLE 14
AVERAGE VALUES OF CONDUCTIVITY OF SATURATED EXTRACT
(EC $\times 10^3$) AND WATER TABLE LEVELS (FT.) FOR
TULELAKE DRAINAGE STUDY 1955-56

Soil depth (ft.)	Value of conductivity				Ave. depth to water 1955 (ft.)	Value of conductivity					Ave. depth to water 1956 (ft.)
	5/25/55	7/26/55	9/15/55	Ave. 1955		6/5/56	7/2/56	8/6/56	9/17/56	Ave. 1956	
League of Nations											
0-0.5	4.18	5.87	6.94	5.66	2.92	5.25	5.38	5.15	4.77	5.13	1.62
0.5-1	3.96	5.08	5.56	4.86		5.24	4.71	4.81	4.25	4.75	
1-2	3.98	4.60	4.73	4.43		4.51	3.81	4.28	4.04	4.16	
2-3	4.15	4.37	4.09	4.20		3.58	2.84	3.78	3.63	3.45	
Frog Pond											
0-0.5	3.95	4.10	3.94	3.99	2.92	2.49	1.92	1.96	1.96	2.39	2.29
0.5-1	3.47	3.60	3.07	3.38		2.26	1.78	1.78	2.02	1.98	
1-2	3.31	3.47	2.99	3.25		2.25	1.83	1.83	2.35	2.48	
2-3	3.29	3.21	2.89	3.13		2.02	1.70	1.70	2.32	2.43	
Southwest Sump											
0-0.5	2.88	2.98	3.68	3.18	2.50	2.80	3.03	3.38	3.14	3.08	1.59
0.5-1	2.67	2.45	2.62	2.58		2.10	1.98	3.04	2.70	2.45	
1-2	2.84	2.72	2.64	2.73		1.80	2.09	2.55	2.79	2.30	
2-3	2.94	3.02	2.95	2.97		1.94	2.20	2.05	2.83	2.25	
Total Area											
0-0.5	3.80	4.43	4.82	5.35	2.84	3.51	3.44	3.49	3.43	3.46	1.83
0.5-1	3.45	3.84	3.76	3.68		3.20	2.82	3.29	2.97	3.07	
1-2	3.39	3.66	3.46	3.50		2.18	2.57	3.06	3.10	2.72	
2-3	3.46	3.53	3.25	3.41		2.51	2.24	2.71	2.96	2.60	

TABLE 15
DISTRIBUTION OF SALINITY IN SOIL PROFILES OF TULELAKE LEASE LANDS

Area of sampling	Lease No.	Date	Conductivity of saturated extracts mmhos/cm								
			0-1½"	½-1½"	1½"-3"	3"-6"	6"-12"	12"-18"	18"-24"	24"-30"	30"-36"
League of Nations.	5	9/15/55	14.80	14.80	9.12	8.48	6.90	6.23	6.01	5.32	4.64
Frog Pond.....	94	9/15/55	7.09	7.51	4.86	4.26	4.64	5.21	5.68	6.23	5.43
Southwest Sump..	10	9/15/55	10.98	12.45	6.90	6.54	6.81	7.40	7.74	7.29	7.74

soils, examination of table 14 indicates that apparently a saline condition exists in the lease lands, especially in the League of Nations.

The monthly maps of salinity show that a large area of the League of Nations contains an unfavorable amount of salt. The leases most affected are 5, 7, 23, 25, and 36. The Frog Pond area appears less badly affected than the League of Nations but nevertheless has specific areas which have high conductivity values. The particular leases affected are numbers 59, 63, 73, 98, and 101. The Southwest Sump also does not appear to be badly affected but because of the small number of samples taken a fairly large sampling error exists. The leases most affected with salt are numbers 10 and 19.

Salinity was lower in 1956 compared to 1955 because, as mentioned above, of the unseasonable amount of rainfall (16.67 inches July 1955–June 1956, compared to 9.97 inches mean for a 24-year period).

The salinity maps also point out that the areas affected with salinity expand progressively throughout the summer. This is especially shown in the League of Nations. The distribution of salinity in the soil profiles at the end of the 1955 season (table 15) shows that the highest concentration of salts is in the first 1½ inches of the surface. In the samples for lease 5, the salt grades continuously down from the surface to the water table but in those from lease 94 salinity again becomes high in the 24–30-inch zone, near the water table. The profile of salinity for lease 10 in the Southwest Sump shows a salinity reduction for the 1½ to 12 inch zones but the concentration again becomes high from 12 to 36 inches. In general, these profiles point out that evaporation from the shallow water tables prevailing throughout causes a build-up of salinity at the surface. If this surface concentration were maintained throughout the winter until spring planting, germination of the

young seedlings would be retarded. For example, if the salinity were maintained at 12 mmhos, germination of barley would be reduced 40 per cent (Richards, 1954). Fortunately winter rainfall reduces the salt content below the fall concentration but, nevertheless, over a period of years, unless immediate preventive measures are instigated, the salinity will probably build up to the point where even winter leaching will not be effective.

The soluble sodium percentage and exchangeable sodium percentage appear to indicate that in general in these areas the hazard of excess exchangeable sodium is not great. For some soils an E.S.P. of 15 per cent is excessive. Few samples indicate a value of this magnitude. It should be emphasized, however, that this value may be unsatisfactory for these soils. Additional field and laboratory investigation would aid in establishing safe values as well as suggesting the particular type of reclamation needed.

Effect of drains on salinity

In order to determine more specifically the effectiveness of the present types of drainage systems for salinity control, studies were made on two locations in the lease lands. The first area investigated was in the Southwest Sump and was studied to determine the effectiveness of the surface drains servicing leases 4, 5, 10, and 11 in salt removal by flushing. The second area of investigation was lease 25 in the League of Nations, studied to determine the ability of the open ditches in the area to remove salt by leaching.

Drains in the Southwest Sump are primarily surface drains designed to remove surface water from the area after pre-irrigation and winter flooding. Since these drains are shallow no drainage is provided for ground water control. Consequently salt removal in the Southwest Sump is mainly accomplished by surface flushing. The area provides an example of the effect on the salt regime of long-term application of water with only sur-

face runoff and consumptive use as means of removing water from the area.

Surface water from leases 4, 5, 10, and 11 in the Southwest Sump is removed by an open ditch bordering the eastern edge of leases 5 and 11, and by a parallel ditch bordering the western edge of leases 4 and 10. In addition, a third open ditch of somewhat larger capacity cuts the southwest corner of lease 10.

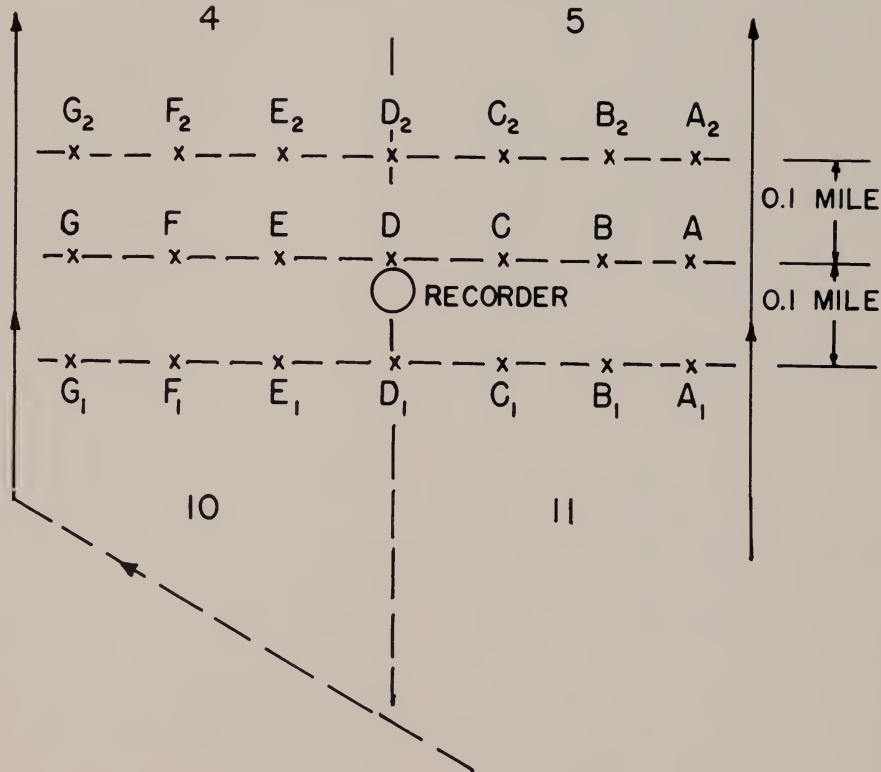
Considerable winter leaching of salt took place in the Southwest Sump during the winter of 1955-56 because precipitation during this period was unusually high, and also because the area was flooded as a flood protection measure. It was possible, consequently, to make a study of the effectiveness of the drains servicing leases 4, 5, 10, and 11 in removing the salt.

Three parallel transects were made across the field between the drains, which are one mile apart. The center transect

was made on the border between leases 4, 5, 10, and 11. The northern transect was made across fields 4 and 5, and the southern transect across fields 10 and 11 (see figure 6). Soil samples were taken at 0.166 mile intervals along each transect for salt determinations. The depths of samples were 0-6 inches, 0-12 inches, 12-24 inches, and 24-36 inches. The conductivity values of the saturated extracts of these samples are shown in Table 16, and are shown graphically in figure 7.

The results indicate that the average salt concentration was above 4 mmhos/cm at every point across the field except immediately adjacent to the east side drain. However, at 0.33 mile from this drain the highest concentration of salt was found. The conductivity decreased as the west side drain was approached but even adjacent to this drain the salt was still above the allowable limit for sensitive crops. Study of the salt distribu-

Figure 6. Sampling locations for detailed salinity study in Southwest Sump, 1956.



tion throughout individual profiles shows that in most cases surface flushing was effective in removing salt only from the first six inches of soil.

The drain cutting the southwest part of lease 10 has evidently contributed somewhat to ground water as well as surface water control; salinity was low in the vicinity of this drain, that is, the salt values at locations E₁, F₁ and G₁ were considerably lower at each depth than values for corresponding depths of samples to the north. In addition, the salt values for samples from the first 12 inches at all of these locations except E₁ are below the critical value of 4 mmhos per cm.

These observations indicate that drains in the Tululake lease lands designed to remove only surface water when coupled with surface flushing are relatively ineffective as a means of maintaining salinity within allowable limits for plant growth. However, where drains provide ground water control in addition to surface water control, the salinity can be maintained at a favorable level.

In the League of Nations and Frog Pond, drains were designed to provide ground water control and, therefore, a study similar to the one in the Southwest Sump was made to determine the efficiency of these drains for lowering the water table after irrigation and for transporting leached salt from the area. The lease selected was number 25 in the League of Nations. An automatic stage recorder was placed at the south center of this lease and continuous records were obtained from June 4 to September 3, 1956. Soil samples were taken each month and salinity determined from the conductivity of the saturated extract.

On June 23, the leasee irrigated this lease seeded only to barley. This irrigation raised the water table more than 2 feet in three days. About three months were required for the water table to drop to the original level. The conductivity values of the soil samples showed that

immediately after irrigation, salts in soil depth of 6-12 inches, 12-24 inches, and 24-36 inches were lowered, but not as much in the 0-6 inch depth. Only at the 24-36 inch depth was the conductivity value lowered below the critical value of 4 mmhos/cm. The values obtained a month after the irrigation were

TABLE 16
DRAINAGE-SALT INVESTIGATION IN
THE SOUTHWEST SUMP

Soil depth (inches)	Location			
Depth	A	A ₁	A ₂	Average
0-6.....	3.20	1.60	2.00	2.26
6-12.....	1.55	1.42	1.21	1.39
12-24.....	1.49	1.75	1.15	1.46
24-36.....	2.40	2.20	1.75	2.12
Depth	B	B ₁	B ₂	Average
0-6.....	6.00	4.50	4.10	4.86
6-12.....	7.50	5.50	5.00	6.00
12-24.....	7.60	5.50	5.50	6.20
24-36.....	6.90	5.60	5.50	6.00
Depth	C	C ₁	C ₂	Average
0-6.....	8.00	5.00	5.00	6.00
6-12.....	9.10	7.00	7.00	7.70
12-24.....	10.00	6.70	8.00	8.23
24-36.....	8.00	6.00	7.00	7.00
Depth	D	D ₁	D ₂	Average
0-6.....	6.00	3.90	4.50	4.80
6-12.....	7.50	5.00	4.60	5.70
12-24.....	8.10	4.90	5.60	6.20
24-36.....	6.50	4.50	5.50	5.50
Depth	E	E ₁	E ₂	Average
0-6.....	4.10	3.90	8.00	5.33
6-12.....	5.00	4.90	9.00	6.30
12-24.....	8.00	5.50	10.00	7.83
24-36.....	8.00	4.10	8.60	6.90
Depth	F	F ₁	F ₂	Average
0-6.....	5.50	1.65	7.00	4.72
6-12.....	5.70	3.10	9.00	5.93
12-24.....	7.50	4.50	6.40	6.13
24-36.....	7.00	4.00	7.00	6.00
Depth	G	G ₁	G ₂	Average
0-6.....	6.00	2.00	5.50	4.50
6-12.....	5.50	2.10	4.70	4.10
12-24.....	6.00	4.90	6.50	5.80
24-36.....	4.90	2.90	6.00	4.60

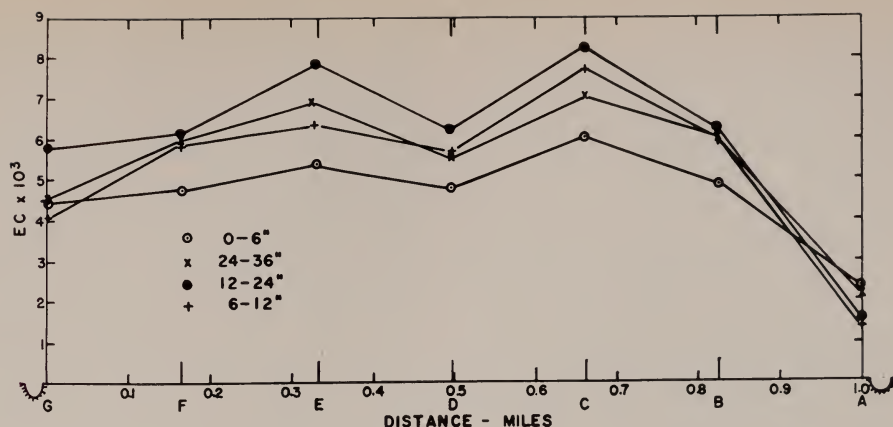


Figure 7. Conductivity of saturated extracts (average of three transects, 0-36 inch depth) as a function of distance. Southwest Sump, 1956.

as high as or higher than those before the irrigation, the greatest increase being in the 0-6 inch depth.

To be beneficial for leaching, the water table must be lowered rapidly after water application, so the salt can be quickly transported away from the area. If this is not accomplished, and the water table stays close to the ground, surface evapotranspiration will result in reaccumulation of salt in the surface zones of soil. Any beneficial effects of leaching will be negated. The above situation existed on this lease and shows that present drains are inefficient. Although the water table rose over 2 feet in three days as a result of irrigation, it took almost three months to lower it to the original level by drainage. The salt concentration was not decreased to an acceptable value at any depth and again reached a high value within a month or so.

The inefficiency of the drains in the League of Nations and Frog Pond is not a result of low capacity; the cross-sectional areas are large enough to handle the volume of drainage effluent. The fault lies mostly with the fact that drains have not been pumped low enough to permit adequate ground water control because of three limiting factors: excessive length of ditches, flat gradient, and algae and moss growth in the ditches restricting

flow. To remedy the situation these factors would have to be eliminated but that cannot be easily accomplished. The experimental work of 1957 and 1958 was aimed at finding satisfactory alternatives.

The study also indicated the difficulty that will be experienced in salt removal by leaching of these soils. Although a fairly large amount of water passed through the 0-6 inch depth and although the irrigation water is of low salt content, the salinity in this depth was not appreciably reduced. Even though drainage is not adequate, the salinity should have been reduced further below the original levels than indicated by the data. It appears, therefore, that to leach these soils effectively large volumes of water must be applied. This conclusion was also reached during the 1958 investigation (see page 54).

Relationship between salinity and water table levels

Where the surface layers of soil are badly affected with salt, one of the first factors considered is the position of the water table. The combined actions of evaporation and plant transpiration result in a suction gradient which causes the movement of water and salts to the soil surface where the salts become concentrated because of the evaporation of

the water. This is shown by examination of conductivity values of saturated extracts of the first 6 inches of soil. The process of evaporation and concentration of salts at the soil surface is carried on most rapidly in the presence of a high water table.

The relationship between salinity and water tables on the Tulalake lease lands for the summers of 1955 and 1956 is summarized in table 14, and the monthly salt-water table maps. The average values for the individual areas for the summer of 1956 are given in table 17.

The League of Nations is developing into a problem area in respect to high water table levels and high salt concentrations. As the maps indicate the regions of extremely high conductivity values coincide closely with the regions of high water table levels. Two apparent reasons for the high water table levels have been discussed before (see page 00)—inadequate drainage because of insufficient depths and capacity of the present drains; and poor irrigation efficiency.

The new leasing program of the Bureau of Reclamation whereby the farmers lease the land for five years rather than one year should make the operators more conscious of the developing situation but education on the proper use of irrigation water is still imperative.

The situation is better in the Frog Pond area. There are certain leases and areas, indicated on the maps, where conductivities are in the harmful region. The correlation between salt and water table levels is not borne out so well on specific sites in this area as in the League of Nations. The average values, on the other hand, show that for the area as a whole the conductivity values are lower and the water tables deeper than in the League of Nations.

The situation in the Southwest Sump is different from that on the other lease lands. The drain ditches in this area are designed primarily for removing surface

water; consequently, water table lowering is provided mainly by evapotranspiration. Water is applied only in the spring for pre-irrigation, so that the water table is originally high and declines slowly through the summer. The surface drains provide for removal of surface salt by flushing but this technique has not proven effective. Consequently, salt is being shuttled up and down in the profile year after year and a gradual build-up is developing. There were two areas (see maps on pages 20, 21, 22) with high levels of salinity during 1955 and 1956, and undoubtedly these areas will grow. Improving drainage by means of ditches or tile designed to control ground water levels and remove leaching water are necessary to avoid a serious salt problem in future years.

Discussion

The average values for conductivity of the saturated extract of soil samples and average values for depth to water for the three main areas of the lease lands, 1955 and 1956 seasons, are shown in table 14. The values for the total area are also indicated. Study of this table shows that for all three areas a slight decrease in conductivity values occurred at every depth in 1956 compared to 1955. On the other hand, the water table levels for each area were high during the summer of 1956 compared to summer 1955. The differences can be largely accounted for by reviewing precipitation records for the Tulalake area (table 10).

For the summer of 1955 the salt values could be expected to be fairly high because winter leaching had been low. Similarly, the water table levels were fairly low because of small accretion from precipitation. On the other hand, because of the excess precipitation in 1955-1956, almost $\frac{1}{2}$ foot above the long-time mean, considerable winter leaching of salt took place, and the water table levels were high most of the season.

Contributing to low salt values on the Southwest Sump was the fact that during the winter of 1956 dikes protecting the area from the water in the restricted sump broke, and flood water covered the area. As much as 5 feet of water stood over some areas. Several auxiliary pumps were brought in and the water was quickly removed, so that rapid removal of salts resulted in a general lowering of salt values for the area.

Conclusions

The first two summers of drainage-salinity investigation on the Tulelake lease lands have revealed a saline type condition throughout much of the area. In addition, a sodium hazard appears to be developing at some specific locations. The League of Nations in particular is affected, and local areas in the Frog Pond and Southwest Sump are also developing salinity problems.

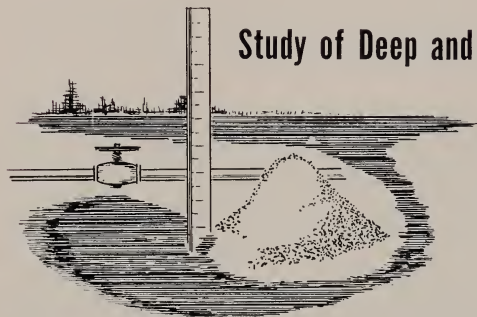
Drainage studies have shown that a high water table prevails throughout

TABLE 17
AVERAGE VALUES OF SALINITY AND
WATER DEPTH, SUMMER 1956

Area	Conductivity EC $\times 10^3$ (0-6 inches)	Depth to water (ft.)
League of Nations.....	5.13	1.62
Frog Pond.....	2.19	2.29
Southwest Sump.....	3.08	1.59

most of the growing season, responsible for the developing salinity problem in the surface soil. Present drains appear to be, on the whole, ineffective in controlling the water table.

Studies on yield and vegetative growth of barley have shown that while vegetative growth is prohibited by moderate quantities of salt, yields are not restricted greatly. Nevertheless, if the salinity is allowed to build up to high levels even the barley yield will be reduced considerably. Potatoes, the other crop widely grown, are restricted in growth by even moderate salt concentrations.



Study of Deep and Shallow Open Drains, 1957

To make a more detailed study of drainage methods to be used on the lease lands, the Bureau of Reclamation decided to dig one large deep open ditch and two shallower open ditches. The objective of the study was a comparison of the deep ditch with the shallow ditches to find out which was the more effective in lowering the water table.

Construction Problems

The large open drain was dug on the

north-south boundary between leases 3, 4 and 9, 10 in the Southwest Sump. The two shallow ditches were about 2,400 feet long and ran east and west on lease 5. Observation wells were installed in a grid pattern about both deep and shallow drains. Eight automatic water stage recorders were installed on a transect perpendicular to the large ditch.

Because the soil of the lease lands becomes semi-fluid when saturated with water, construction techniques become

very important to insure a stable ditch of uniform cross section.

The large ditch was carefully dug to a depth of 8 feet during the winter months and remained full of water until the following spring. A sump pump was placed at one end of the ditch and the water was pumped out of the ditch and into a higher-level ditch from which it was pumped into the lake. The ditch was constructed with a dragline and had a berm of 15 feet.

In the spring of 1957, the pump was turned on at a low rate of speed in order to slowly lower the water in the ditch. The water level gradually receded until it reached the bottom of the ditch. At that time the ditch began to fail.

The sides of the ditch slumped vertically, leaving large cracks in the ground and simultaneously, the bottom of the ditch rose vertically (see figure 8). The soil movement was so gradual that it appeared to be imperceptible to the eye. The entire movement took place over a

period of several hours. It resembled the flow of molasses. The failure of the ditch was caused, not by the slumping of the sides into the ditch, but by the movement of the semi-fluid soil material according to well-established laws that govern such movement. The problem arose because the water was removed from the ditch while the water table in the adjacent soil was close to the soil surface. This meant that the water in the soil adjacent to the ditch stood at a level of about 7 feet above the bottom of the ditch. The weight of the water was exerted downward in such a way that it caused the bottom of the ditch, which lacks stability, to rise. Observations in the Tulelake area indicate that this is a common reason for the failure of ditches. It also indicates the need for a great deal of care when ditches are dug 4 or 5 feet or more below the ground surface.

A possible alternative method of construction would be a repeated deepening of the ditch. The ditch is initially dug to,

Drain in Southwest Sump (1957). Experimental section is beyond the sump and pump.
Drain is full of water from winter floods.



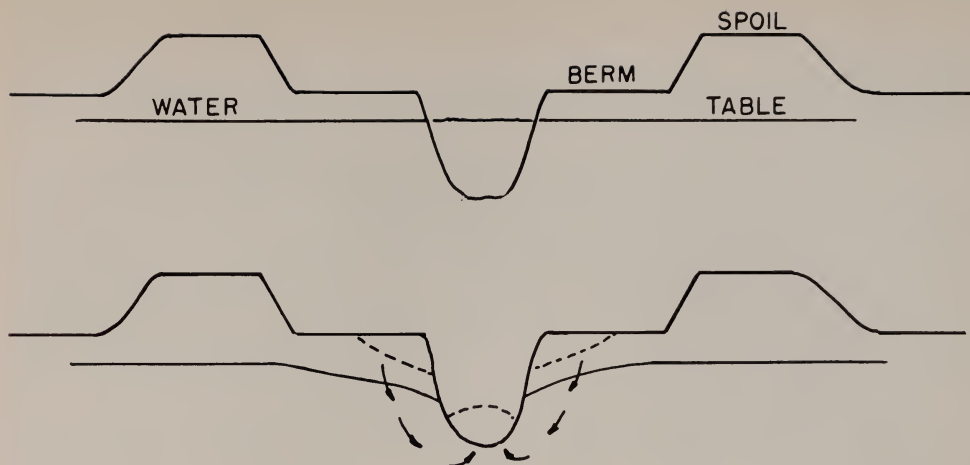


Figure 8. Diagram of ditch failure following removal of water from ditch. Top diagram shows ditch before water is removed. Bottom diagram illustrates movement of soil following removal of water. Sides of ditch move vertically downward and bottom of ditch moves upward.

say, 3 or 4 feet below the ground surface. After the water table has drained to the bottom of the ditch, equipment is brought in to deepen the ditch another foot or so. The water table is again allowed to drop below the bottom of the ditch, and equipment is again brought in to deepen the ditch still further.

Other field observations have indicated that ditches as shallow as 4 or 5 feet will fail in a similar manner if water is allowed to pond close to the edge of the ditch. The situation could occur where an irrigation canal runs adjacent to a drainage ditch. The pressure of the water in the canal will cause the drainage ditch to fail.

After the failure of the open drain, the equipment was brought back and the ditch was deepened once again, so that at the end of the construction period the ditch stood about 6 feet deep below the ground surface.

Effect of Deep Drains on Water Tables

Perpendicular to the ditch at three different locations a line of observation

wells were installed. On the center line of these observation wells automatic recorders were installed at various locations to provide a continuous record of water table fluctuations adjacent to the ditch.

Records obtained from the observation wells and automatic recorders indicated the position of the water table on different dates during the growing season.

The most noticeable feature of these charts was the flatness of the water table. Drawdown near the ditch occurred within 10 to 15 feet from the ditch and there was very little curvature to the water table.

Two conclusions can be drawn from the observations adjacent to the single deep drain.

1. The surface soil layers have a high hydraulic conductivity. This was confirmed by other tests made using the piezometer-method of determining the hydraulic conductivity.
2. A single drain does not provide the information needed for the design of a drainage system in such soils.



Collapse of experimental drain. Note how bottom of ditch has risen.

While the experiment did not indicate anything about the drain spacing, it did point out the difficulties of constructing and maintaining open drains in the Tulelake area, and it also pointed out some techniques that can be used to establish a system of open drainage ditches on the lease lands.

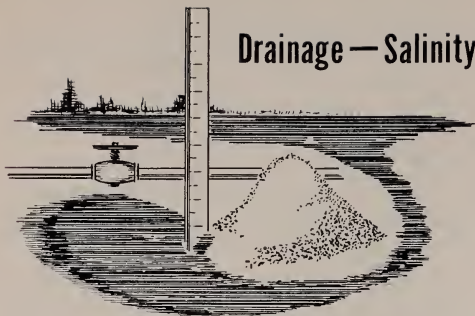
Shallow Drains

The shallow drains which were placed about 4 to 5 feet below the ground surface did not encounter the same type of difficulty encountered with the deep open drains. According to the records, the shallow drains were quite effective in lowering the water table rather quickly in the spring. While the instrumentation on the shallow drains was not as complete as on the large deep drains, the results indicate that the shallow drains lowered the water table two to three times as fast as the adjacent large deep drain.

Observations made in the fall showed that the water table was well below the bottom of the shallow drain, indicating that the large deep drain may have had some influence on lowering the water table over the entire area. Another factor influencing the drop of the water table would be crop use of the ground water. The crops extracting water from the soil will cause the water table to drop as this water-table water is used by the plants.

Conclusions

The studies of 1957 showed that the use of deep drains (6 feet or deeper) is limited due to the unstable soil conditions that prevail in the Tulelake area. The use of shallow drains (4 to 5 feet deep) is probably feasible for the lease lands. In addition, the results indicated that conclusions regarding drain spacings cannot be based on the observations adjacent to a single drain.



Drainage — Salinity Investigation, 1958

The drainage investigation in 1957 showed that deep drains are difficult to maintain because of the inherent instability of the soil. Techniques other than those used in 1957 will have to be developed if open drains are to be used on the lease land.

Because of the failure of the open drains in 1957, the 1958 studies investigated the use of tile drains as a means of controlling the high water table and of removing leaching water used for reduction in salinity.

In addition, it was felt that results of a drainage-salinity study on an individual lease would lead to some general recommendations for reclamation of other affected areas in the lease lands. For these reasons, a 78-acre lease unit with a high level of soil salinity and high water table was obtained by the U. S. Bureau of Reclamation for experimental use in 1958.

The objectives of the drainage investigation were to determine for the Tulelake lease lands:

The most efficient spacing of tile drains.

The most efficient and practical tile size.

The most efficient and practical type of backfill material.

To achieve these three objectives it was necessary to determine:

The water table conditions throughout

the field by means of observation wells and automatic recorders.

The rate of drawdown of water table and the distance water table is lowered with drainage.

The quantity of effluent handled by each drain.

The objective of the salinity investigation was to relate removal of salt from the soil to volume of water applied, volume of water removed by the tiles, and methods of leaching, without cropping. To achieve this objective it was necessary to determine:

The volume of leaching water applied and volume removed.

Salinity conditions throughout field prior to leaching.

Salinity at approximately midpoint of leaching treatment.

Salinity at end of leaching treatment.

Drainage Investigation

Procedures and materials.

The effect of tile drains as a means of controlling the water table was studied at the 78-acre lease. A system was designed to obtain information on tile sizes, spacing, and backfill material. Because the area available for this study was limited, it was not possible to conduct the experiment with the controls usually established in an investigation of this kind. In addition, two of the tile lines developed physical difficulties during the

season so that the measure of control attempted was upset. The results should, therefore, be studied from a qualitative rather than a quantitative viewpoint—as a demonstration of the applicability of tile lines as a means of drainage rather than one giving exact information that could be statistically analyzed.

Six tile lines were installed at a depth of about 5 feet in the test lease in March 1958 with the following variables (see figure 9) :

Spacing. Three different spacings were included: 220 feet, 440 feet, and 660 feet. Lines A and F were intended to act as guard lines cutting off flow into the area from the south and north, respectively, and flow out of the area during leaching trials.

Tile size and length. Three variable tile sizes were used: 4-inch, 6-inch, and 8-inch. The length of each line was 1,200 feet, but two lines were split into two 600 feet tile sizes.

Tile materials. Two different materials were tested for use as drain tubes: bituminous fiber and nonreinforced concrete. The bituminous fiber pipe contained two parallel rows of $\frac{5}{8}$ -inch holes 100 degrees apart to permit water entry into the line. Eight-foot lengths of fiber pipe were used with adjacent lengths joined by means of couplers. The fiber pipe used to make road crossings was heavy duty and unperforated.

The concrete pipe was of tongue and groove construction. This type of pipe provides a better alignment between adjacent tile than with square-cut end tile. Water enters the line through the gap between the tongue and groove of adjoining tubes. The length of individual pipe in this experiment was 3 feet.

Backfill material. Three types of trench backfill material were tested:

Type A

- (a) Topsoil placed over tile to a minimum depth of 24 inches above bottom of ditch, obtained adjacent to trench

or separated from unclassified ditch excavated material.

- (b) Unclassified excavated material placed on top of topsoil and used to fill remainder of ditch.

Type B

- (a) Pit-run volcanic cinder placed in trench 4 inches below and 4 inches above the tile.

- (b) Excavated material used to fill remainder of trench.

Type C

- (a) Excavated material used to fill entire trench.

Filter material. Twelve hundred feet of type "A" or "C" drain contained a 12-inch-wide strip of fiberglass filter placed above and an 8-inch strip placed below the tile.

Slope. The slope of all lines was the same, 0.001.

The specifications of the individual tile lines are given in table 18.

Tile outflow measurement. In an investigation of the effect of tile drains on water table levels and salt removal by leaching it is important to obtain a measurement of the quantity of effluent. The simplest method of measurement consists of using a bucket and a stopwatch; more complex arrangements make use of weirs or slotted tubes in conjunction with automatic recorders. For the tile drainage investigation at Tulalake slotted tubes were used. The slotted-tube device was developed and tested at the Minnesota Agricultural Experiment Station and reported by Larson and Hermsmeier (1958). It consists of a tube in which is milled a slot. The tube is mounted vertically on the end of the tile line with the slot directed upstream. A hose connects the bottom of the tube to a stilling well on which is mounted an automatic recorder. The water level in the well measured from the pipe invert is the index of discharge. The head measured in this manner is

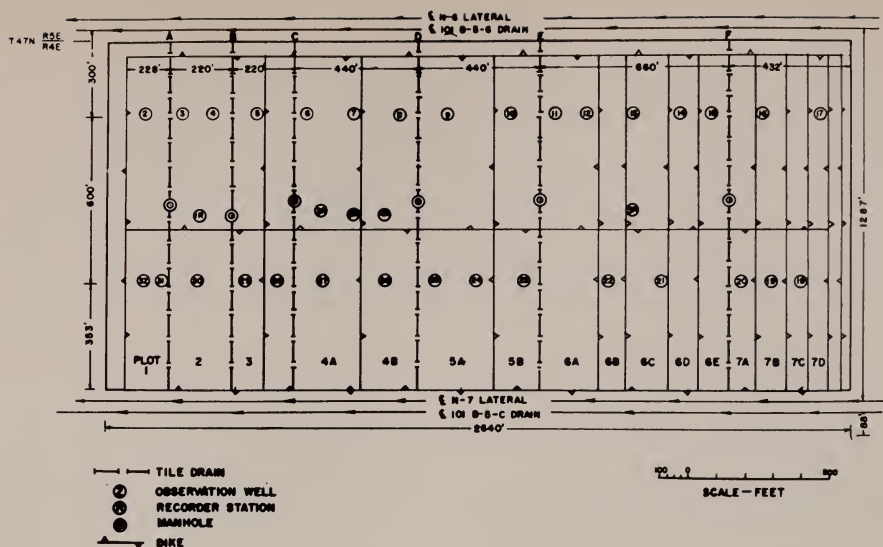


Figure 9. Plot layout for Tulelake study, 1958. North is to the right.

approximately equal to the depth plus velocity head of water flowing in the pipe which, in turn, corresponds to the total flow energy. Calibration curves may be obtained by mounting each slotted tube on a test pipe in a hydraulic laboratory and plotting head values corresponding to a range of flow values. If automatic recorders are used with the tubes mounted on the tile line in the field, a continuous record of heads is obtained which can be converted into continuous flow values by means of the calibration curve.

A slotted-tube device with stilling well and Stevens Type F automatic recorder was mounted on each tile line except line F during the period of the investigation. The recorders were equipped with weekly clocks. The relation between head in the stilling well and the pipe invert was determined by surveying with level and rod. The weekly records of head values were converted to flow values by means of the calibration curve obtained for each slotted tube.

Results

Tile spacing. From July 29 to August 13, leaching of the test plots was discon-

tinued to permit determination of the effect of tile spacing on drawdown of the water table. The water table profile for this period is shown in figure 10 and tile outflow values shown in figures 11 to 15. On July 31, the water table was still at the surface on leases 2, 3, 6A, 6B, 6C, 6D, 6E, and 7A as a result of irrigation. The water table shows a slope toward tile D from both directions, indicating that it was receiving flow from both the north and south irrigated areas. The tile flow values at this time show that line A was handling the largest volume of water and was flowing full and under pressure. Line C was essentially inoperative.

On August 1, the water table was still at the surface on plots 6A and 7A and sloped to the south toward line D where the depth to water was about 3.25 feet. The water table on plots 2 and 3, on the other hand, had dropped to about 2.5 feet below the surface and sloped from observation well 5 to the approximate water table midpoint between lines A and D north toward line D and south toward line A. The flow data indicate that lines A and D were handling the largest volumes of water. The flow for line A at this time was 37 gpm lower

TABLE 18
SPECIFICATIONS OF TILE LINES IN TULELAKE TEST PLOT—1958

Tile line	Length (ft.)	Tile size (in.)	Tile material	Backfill material	Slope
A.....	1,200	4	Bit. fiber	Type B	0.001
B.....	600	6	Concrete	Type C	0.001
	600	4	Bit. fiber	Type C	0.001
C.....	1,200	4	Bit. fiber	Type A	0.001
D.....	600	8	Concrete	Type B	0.001
	600	6	Concrete	Type B	0.001
E.....	1,200	6	Concrete	Type A	0.001
F.....	1,200	8	Concrete	Type A	0.001

than on the previous day because of the drop in head.

On August 3, the water table in plots 6A and 6B had dropped to 2.00 feet below the surface and the water table gradient was still toward line D. Near lines A and D the water table was about 3.50 feet below ground surface, and about 3.00 feet below the surface at the

midpoint. The midpoint between the lines had now moved toward line D. Lines D and A were handling the largest volume of flow but the quantities were less than on the previous date commensurate with the lower head. Line B was still removing a fair quantity but by no means the amount that could be removed if the line were functioning properly.

Discharge of drain pipe during leaching. A slotted tube is used to measure the discharge. (Because the tile line is carrying water under pressure, the slotted tube shown here is not operating properly.)



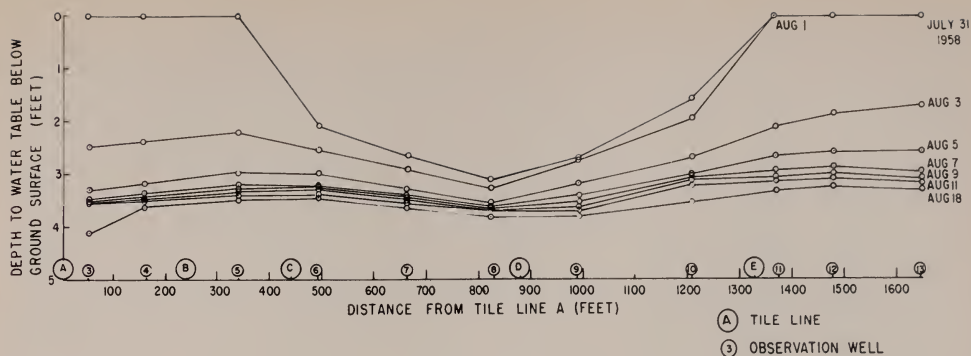


Figure 10. Drawdown of water table by lines A, B, C, D, and E during period July 31 to August 18, 1958, after cessation of irrigation on test plot.

By August 5, the water table in plots 6A and 6B had dropped an additional 0.65 feet to a depth of 2.65 feet. The slope was still toward line D. The water table was about 3.60 feet below ground surface near lines A and D and about 3.10 feet below the surface near the midpoint. Flow had decreased 75 and 100 gpm in lines A and D, respectively, from the previous date.

As figure 10 indicates the water table fell quite slowly after August 5. On August 18, the day before resumption of irrigation, the water table on plots 6A and 6B was about 3.35 feet below the surface. The water table in the vicinity of line A, according to the reading in well 3, was about 4.15 feet below the surface. Near Line D the level was about 3.75 feet and level at midpoint about 3.45 feet. The flow in all lines was very low, with line A removing the largest volume. The rise in flow in line A at this time was caused by irrigation in the lease to the south.

Tile outflow data. The total quantity of water applied to the plots and the total quantity removed by the individual tile lines (except line F) are given in tables 19 and 20. In addition, the outflow hydrographs for each line are shown in figures 11, 12, 13, 14 and 15. The flow hydrograph for line F was not obtained and, therefore, the total shown in table 20 is short the amount needed for this

line. Nevertheless, the quantity of effluent from the individual lines can be compared with the amount of water applied to the individual plots, to obtain an estimate of the efficiency of the various lines. Thus, on the plots between lines A and C, 75.8 acre-feet were applied. Line C was inoperative, and lines A and B removed 38.70 and 16.80 acre-feet respectively. The total for these two lines was 55.0 acre-feet. The remainder was probably removed by line D or by side losses. Line B was partially plugged so that line A removed the greater quantity. Between line C and about halfway between lines D and E, 65.3 acre-feet were applied. Line D removed 73 acre-feet, indicating that it probably handled part of the flow that should have been removed by lines C and E. From the approximate midpoint between lines D and E and lines E and F, 56.4 acre-feet were applied. Line E removed only 20.4 acre-feet, showing that either this line was partially plugged or that the type of backfill did not permit effective drainage.

Automatic recorder data. The graphs of fluctuation of water table obtained from the automatic recorders are presented in figures 16, 17, 18, 19 and 20. Figure 16, for recorder No. 1, situated midway between lines A and B, shows that prior to the beginning of irrigation, the water table had receded to a depth of 4.0 feet below ground surface. During

TABLE 19
QUANTITY OF WATER APPLIED, TULELAKE EXPERIMENT PLOT 1958

Plot No.	Flume	Date of irrigation	Acre-ft. applied	Plot No.	Flume	Date of irrigation	Acre-ft. applied
2	1	July 22.....	1.373	5A	1	June 30.....	3.341
	2	.....	4.100		2	.....	3.859
	1	July 25.....	1.624		1	July 16.....	3.351
	2	.....	0.067		2	.....	3.861
	1	July 28.....	1.084		1	August 26.....	6.361
	2	.....	2.718		2	.....	6.814
	1	August 19.....	0.787				
	2	.....	0.941			Total.....	27.587
	1	August 25.....	.....				
	2	.....	5.785		1	June 27.....	0.710
	1	August 28.....	1.678		2	.....	2.322
	2	.....	2.378		1	July 15.....	3.478
	1	September 1.....	4.075		2	.....	3.550
	2	.....	.....		1	August 22.....	4.034
					2	.....	4.034
		Total.....	26.610		1	September 2.....	3.486
					2	.....	3.486
3	1	July 7.....	0.696	6A		Total.....	25.100
	2	.....	0.501		1	July 10.....	4.805
	1	July 8.....	4.998		2	.....	4.622
	2	.....	5.824		1	July 29.....	1.964
	1	July 21.....	3.465		2	.....	1.761
	2	.....	3.575		1	August 20.....	2.633
	1	July 25.....	1.465		2	.....	2.516
	2	.....	1.300		1	September 2.....	2.689
	1	July 28.....	2.530		2	.....	2.400
	2	.....	2.204				
	1	August 18.....	4.201			Total.....	23.390
	2	.....	3.606				
	1	August 25.....	2.510		1	July 11.....	2.946
	2	.....	3.174		1	July 29.....	2.447
	1	August 28.....	3.629		1	August 20.....	2.444
	2	.....	3.093				
	1	September 1.....	2.401			Total.....	7.837
	2	.....	.....				
		Total.....	49.172	6C	1	July 11.....	3.234
4A	1	July 7.....	0.251		1	July 29.....	3.545
	2	.....	0.339		1	August 18.....	2.963
	1	July 8.....	2.433				
	2	.....	2.941			Total.....	9.742
	1	July 18.....	1.276				
	2	.....	1.816		1	July 11.....	2.484
	1	August 29.....	2.875		1	July 25.....	0.557
	2	.....	2.383		1	July 28.....	3.244
					1	August 19.....	3.098
		Total.....	14.304				
						Total.....	9.383
4B	1	June 30.....	.....				
	2	.....	0.951		1	July 12.....	0.448
	1	July 3.....	2.933		1	July 14.....	2.970
	2	.....	4.350		1	July 25.....	0.131
	1	July 17.....	2.672		1	July 29.....	3.910
	2	.....	3.249		1	August 19.....	3.905
	1	August 27.....	4.147				
	2	.....	3.869			Total.....	11.364
		Total.....	23.390		1	July 12.....	0.191
					1	July 14.....	1.393
					1	July 29.....	1.490
						Total.....	3.074

Total water applied, 229.733 acre-feet.

TABLE 20
 QUANTITY OF EFFLUENT FROM TILE
 LINES—TULELAKE EXPERI-
 MENTAL PLOT—1958

Tile line	Quantity of effluent (acre-feet)	Tile size (inches)	Tile length (ft.)
A.....	38.20	4	1,200
B.....	16.80	6 and 4	1,200
C.....	4.46	4	1,200
D.....	72.66	8 and 6	1,200
E.....	20.40	6	1,200
F.....	.....	8	1,200
Total.....	152.52		

the shut-off period, August 1-18, the water table reached an equilibrium depth of about 3.50 feet. The difference in equilibrium values indicates the possibility of flow into the area from outside areas during the irrigation season. The average slope on the drop-off curves was about 0.9 feet per day to a depth of 3.0 feet showing that it would require about three days for the water table to drop to a depth usually considered safe for crop growth, and prevention of salt transport by evaporation.

The shape of the curves obtained from recorders 2, 3, and 4, located between lines C and D are fundamentally the same as that for recorder 1. However, it is possible to determine the direction of slope of the water table from the differences in heights of the peaks. For example, on August 18 and 19, after the shut-off period, an irrigation was applied to plots 2 and 3. The peaks produced on the recorders were as follows: No. 1, 0.80 feet; No. 2, 1.58 feet; No. 3, 2.35 feet; No. 4, 2.75 feet. Since the depth to water increases from south to north, it is evident that a slope occurs toward line D and that the area of influence of this line is great. The average slope of the drop-off curves of these recorders was about 1.10 feet per day, again showing that the water table is rapidly lowered to a safe level.

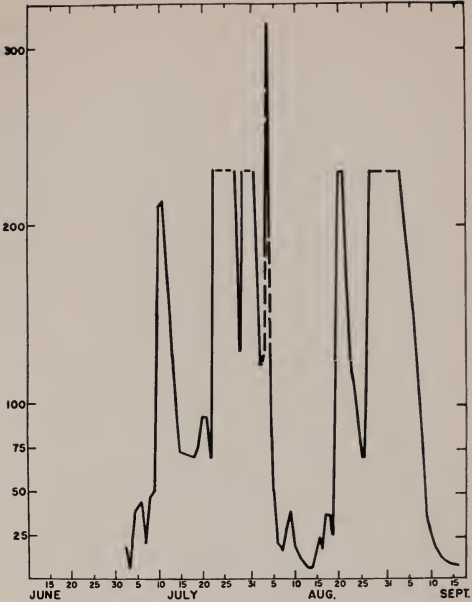


Figure 11. Discharge (gpm) from tile line A, 1958.

The average drop-off slope for recorder No. 5, located midway between lines E and F, was 0.60 feet per day. Five days would be required for the water table to drop to a safe level. The slow rate of drop may have been caused in part by partial plugging of line E.

Discussion

Installation. The failure or partial failure of some of the tile lines in the 1958 drainage investigation points out the need for selection of the most favorable installation time. The test lines were installed in March—the time of a high water table. Since the tile was installed below the water table, it was difficult for the workers to be certain of proper joints between adjacent tile. It appears, therefore, that the best time of installation would be in the late summer or early fall, immediately after harvest, when the water table is naturally low. In addition, it appears advisable to dig all the outlets first, particularly if they are to cross roadways which are compacted to the extent of that of the test plot. This will

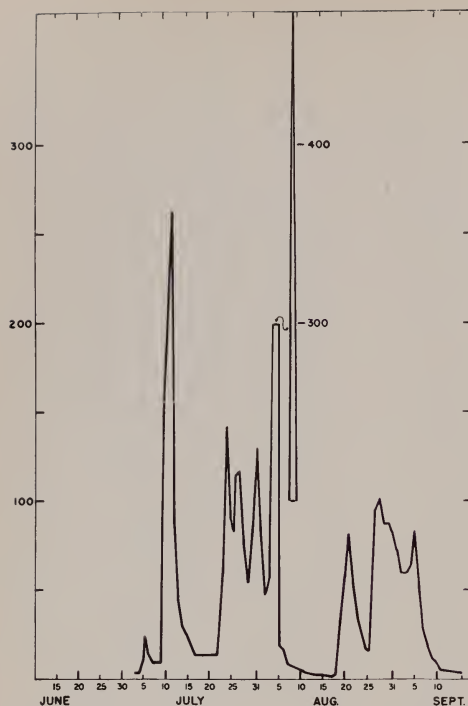


Figure 12. Discharge (gpm) from tile line B, 1958.

TABLE 21

AVERAGE RATES OF DROP OF WATER
TABLE AUTOMATIC RECORDERS
AND OBSERVATION WELLS

No.	Average rates of drop (ft. per day)	No.	Average rates of drop (ft. per day)
Recorders		Observation wells—Cont.	
1.....	0.9	14.....	0.5
2.....	1.0	15.....	0.4
3.....	1.6	16.....	0.6
4.....	0.85	17.....	0.2
5.....	0.6	18.....	0.25
Observation wells		19.....	0.2
1.....	1.1	20.....	0.3
2.....	1.2	21.....	0.45
3.....	1.2	22.....	0.7
4.....	1.2	23.....	0.8
5.....	1.8	24.....	0.8
6.....	0.8	25.....	1.3
7.....	1.1	26.....	0.9
8.....	0.9	27.....	0.8
9.....	0.8	28.....	0.8
10.....	0.97	29.....	0.8
11.....	1.8	30.....	1.4
12.....	0.8	31.....	0.85
13.....	0.8	32.....	0.9

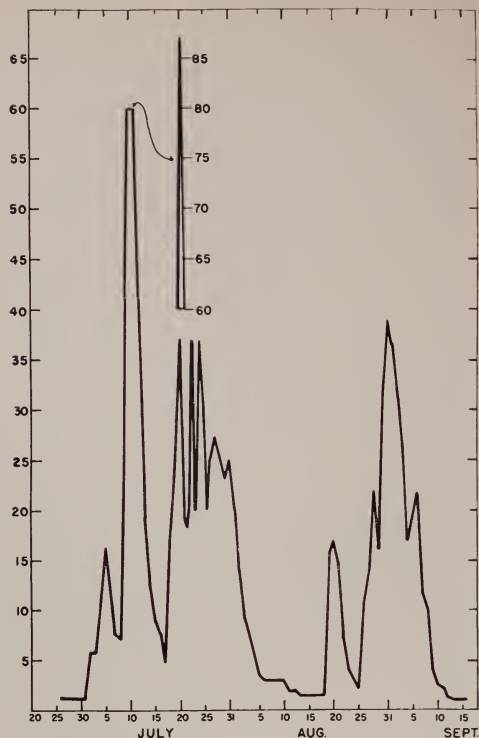


Figure 13. Discharge (gpm) from tile line C, 1958.

provide lowering of the water table prior to installation.

Tile line spacing. The partial plugging of lines B and C limits evaluation of range of influence of the various sized lines and effectiveness of tile size and backfill. The irrigation shut-off period, August 1–18, however, permitted observations of a general nature. Line A, the 4-inch bituminous fiber line with Type A backfill, flowed full and under pressure during the time that adjacent plots were leached. After water application ceased, the water table fell at a fairly rapid rate, and the midpoint of the water table between lines A and D, if lines B and C are considered practically inoperative, was about 450 feet north of line A. This would imply that if 4-inch lines were installed, a spacing of about 900 feet would provide effective drainage. To permit a measure of safety, however, it would

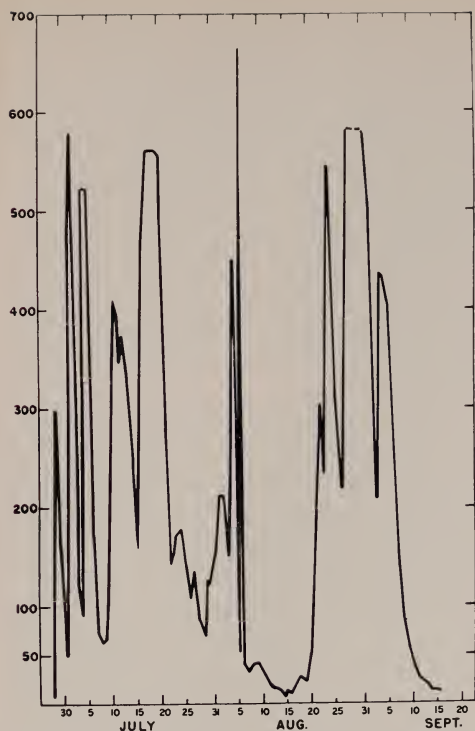


Figure 14. Discharge (gpm) from tile line D, 1958.

probably be better to install lines at about 600 feet spacing.

Line D, the 6- and 8-inch concrete line with type B (volcanic cinders and excavated material) backfill appeared to be the most effective line in operation. This is evident from the tile effluent data which show that it removed the largest volume of water, and from the draw-down curves during the shut-off period. The volume removed by this line was almost twice as much as line A, the next most efficient line. The midpoint of the water table between this line and line A was about 450 feet to the north of A; however, the water table slopes indicated a movement toward line D for about 600 feet. This would indicate that if 6- and 8-inch combination tile lines were installed, a spacing of 1,200 feet would permit adequate water table control. Again, for safety, however, a spacing of 600–800 feet would appear advisable.

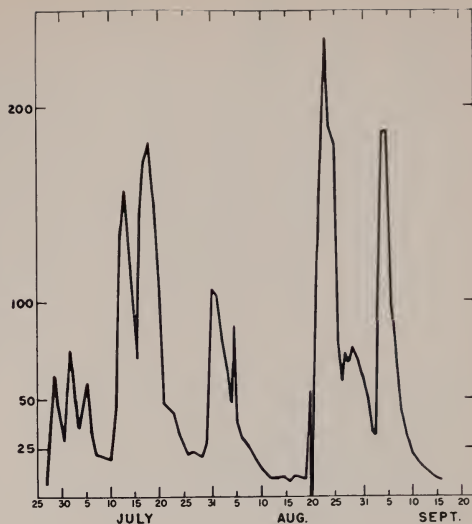


Figure 15. Discharge (gpm) from tile line E, 1958.

Rate of drop of water table. The effectiveness of the tile lines in lowering the water table after irrigation is best seen by comparing them with open ditches. For example, the study on lease 23 for 1956 showed that, where open ditches were used, almost three months were required for the water table to return to the original level after an irrigation. The experimental tile lines, on the other hand, were capable of lowering the water table to 3 feet in three to five days.

Salinity Investigation

Procedures

Plot division. The 78-acre lease was divided into 16 small plots for ease of irrigation and sampling. The size and arrangement of the plots are shown in figure 9. Because of the high infiltration rate of the soils each plot was divided into two halves by a border at midlength, to obtain complete coverage. In this way the upper half of the plot was allowed to fill before the water ran onto the bottom half.

Irrigation supply and equipment. The irrigation water for the investigation was obtained from the N canal at a head gate;

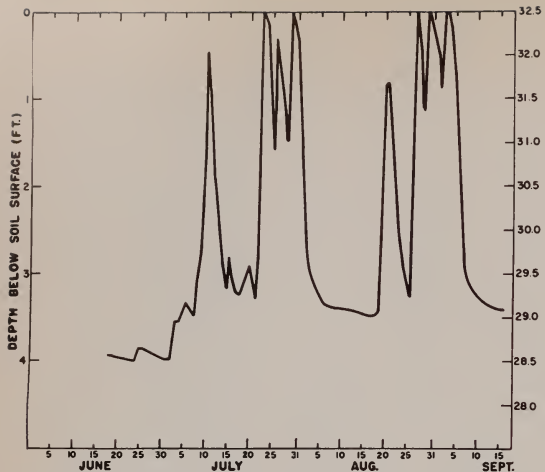


Figure 16. Water table fluctuations at Recorder No. 1, 1958.

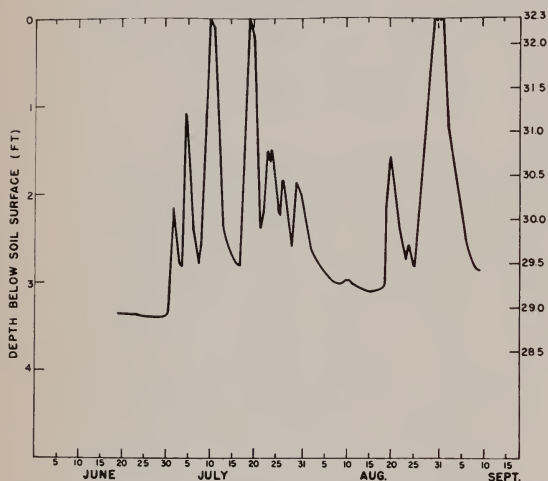


Figure 17. Water table fluctuations at Recorder No. 2, 1958.

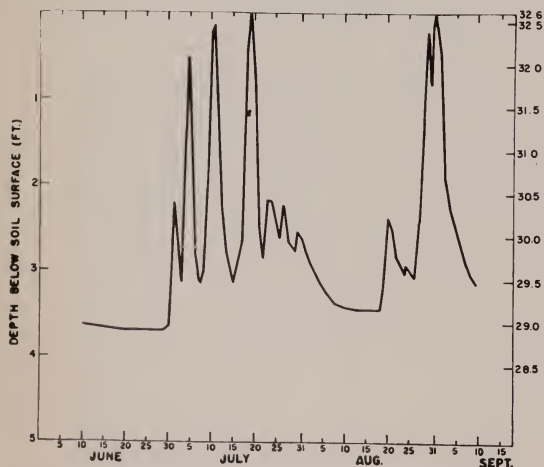


Figure 18. Water table fluctuations at Recorder No. 3, 1958.

it provided water to the supply lateral serving only the test lease and lease 32 to the south. Water was obtained on demand, except when water was desired for irrigation of lease 32. A head ditch was constructed on the east side of the lease and water diverted into it from the adjacent parallel supply lateral through a turnout structure at the northeast corner. A coarse adjustment of head was obtained at the N canal head gate, and fine control at the gate in the turnout structure.

Because seepage from the head ditch into the plot would have prevented accurate measurement of volume of water applied, a plastic film ditch liner was installed in 1,200 feet of the head ditch above the portion of the field to be heavily irrigated. A special liner was constructed consisting of a 54-inch wide, 2.85 mil thick green vinyl film edge-glued to a 54-inch wide, 1.85 mil thick white vinyl film. The final width of the liner was about 9 feet. The thicker green portion of the liner was laid down on the west side of the ditch where the Parshall measuring flumes were later installed.

Eleven Parshall flumes were installed in the ditch bank so that accurate measurements could be made of the quantity of water applied to each test plot (see photo on page 46). The throat width of these flumes was 9 inches. For measurement of head, one staff gauge was mounted on the side of each flume at the upstream end, and another on the side at the bottom of the inclined portion. With these measuring devices only measurement of the upstream gauge was needed with "free flow," that is, when elevation of water in the downstream end of the throat section was not high enough to cause restriction of flow because of the development of backwater. During "free flow" head values were converted to flow values by use of table 8 in University of California Circular 473 (Scott and Houston, 1959). However,

when the flow was great enough to cause submergence (when the ratio of the downstream to upstream heads exceeded 0.7), a correction was applied, using the correction factor from Circular 473. To obtain a tight fit between the flumes and the vinyl ditch lining, the ditch bank was cut to form-fit the flume and the lining cut and folded back into the cut. The flume was then placed in the cut, and sand bags and soil tamped into the space between the outside of the flume and the cut.

Water flow into the flumes was controlled by gates in the flumes themselves and also by canvas dams in the head ditch. During the time each plot was leached, frequent measurements were taken of the heads in the flumes so that a fairly accurate determination of the volumes of water applied could be made.

Leaching operation. Each of the test plots was leached several times throughout the season; however, most of the water was applied to the southern plots where the salinity was the highest. It was not possible to keep plots continually flooded for a long period of time, although several plots were leached for a period of two or three days.

Soil sampling. Soil samples for salt determination were taken three times during the period of the investigation. The first samples were taken in the vicinity of each observation well in March 1958, immediately before installation of the tile lines. The second set of samples was taken near the observation wells and at other locations in each plot in mid-July, after several plots had been irrigated. The third set of samples was taken in each plot near the wells and at additional locations in September, after all irrigation had ceased. A fourth and fifth sampling was made in April and September 1959. The soil samples were analyzed for salt content by the conductivity of the saturated extract method.

Water sampling. Twenty-five times during the period of the investigation

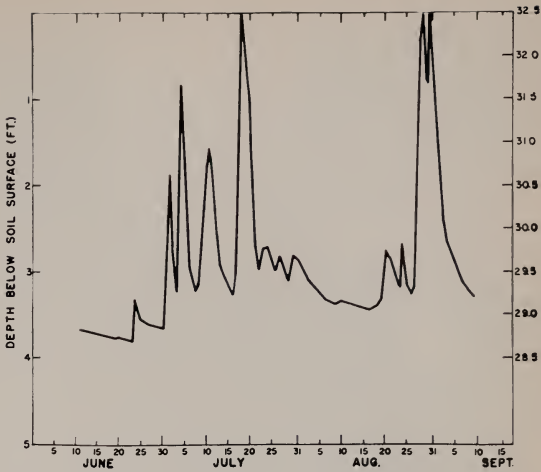


Figure 19. Water table fluctuations at Recorder No. 4, 1958.

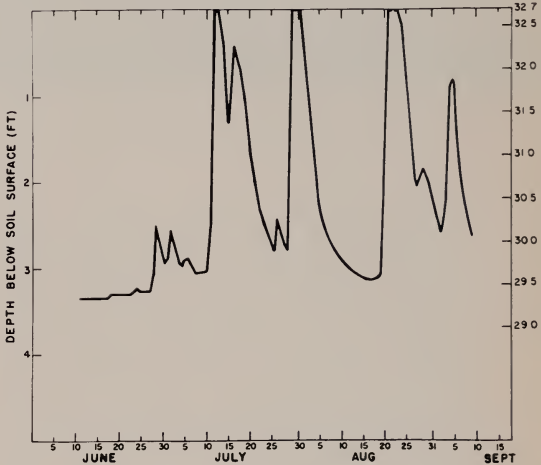
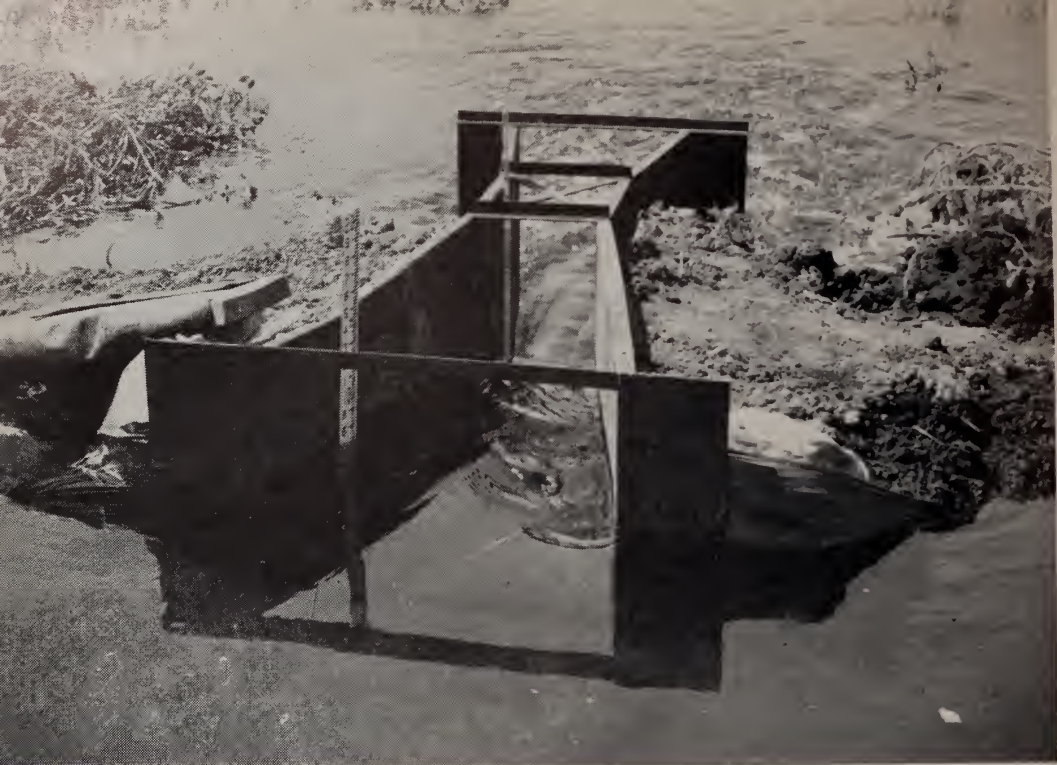


Figure 20. Water table fluctuations at Recorder No. 5, 1958.

water samples were obtained from the tile outlets. A complete chemical analysis was made on some of the samples; for the others only conductivity was determined. In addition to the tile water samples others were obtained at N canal at the turnout gate.

Determination of effectiveness of leaching. The data on quantity of water applied, together with salinity data at beginning, midseason, and end of the



Venturi-type flume used to measure the amount of leaching water applied to the field.

leaching trials, provide a means of determining the efficiency of the leaching technique. The ratio of salt concentration in the soil solution after a period of leaching, to initial salt concentration (C/C_0) is made for each sampling site. This ratio is plotted against a second ratio, depth of leaching water used to reduce salinity from C_0 to C per unit depth of soil. The resulting curve provides an indication of the depth of water per unit depth of soil required to reduce the salinity to any given level.

To obtain concentration units (meq per liter) for conductivity units (mmhos per cm) it is necessary to plot the corresponding values for a number of samples on which complete analyses have been made. Knowing the conductivity values for saturated samples it is then possible to determine the concentration values by consulting the graph.

The ratio of the depth of leaching water to the depth of soil is obtained

from a knowledge of the amount of water applied, area of the plots, and depth of leaching.

Effect of rainfall. Some leaching results from rainfall during the winter months. In some areas this leaching represents an important contribution in maintaining a favorable salt balance in the root zone. To evaluate the leaching by rainfall, soil samples were collected in the spring of 1959 for analysis at the sites of previous sampling.

During the 1959 crop year, barley and potatoes were grown in the area of investigation. Soil samples were again taken in the fall of 1959 to estimate changes in soil salinity following cropping.

Results

Relationship between volume of water applied and volume removed. The total amount of water applied to each plot

during the 1958 investigation is given in table 19, and the total volume removed by the tile lines in table 20. A greater quantity was applied to the southern plots because of the higher salt content in this area. As mentioned before, the total volume of tile effluent is short by

the amount removed by line F. If it is assumed that this line removed an amount equal to that of line E (20 acre-feet), the total removed is still about 60 acre-feet less than the total applied. Reasons for the difference may have been difficulties in measuring tile outflow (see

TABLE 22

TULELAKE DRAINAGE-SALINITY STUDY CONDUCTIVITIES OF SATURATED EXTRACTS—TULELAKE, CALIFORNIA, MARCH, 1958

Sample No.	Depth (ft.)	mmhos/cm	Sample No.	Depth (ft.)	mmhos/cm	Sample No.	Depth (ft.)	mmhos/cm
1.....	0-1 1-2 2-3 3-5 Ave.	7.73 7.19 6.88 6.72 7.13	12.....	0-1 1-2 2-3 3-5 Ave.	3.51 5.25 5.32 5.11 4.80	23.....	0-1 1-2 2-3 3-5 Ave.	1.24 4.08 2.85 2.73
2.....	0-1 1-2 2-3 3-5 Ave.	 7.93 7.73 7.42 7.69	13.....	0-1 1-2 2-3 3-5 Ave.	2.39 4.50 4.64 5.13 4.16	24.....	0-1 1-2 2-3 3-5 Ave.	4.96 4.43 4.49 4.64 4.63
3.....	0-1 1-2 2-3 3-5 Ave.	10.41 9.71 8.09 8.25 9.11	14.....	0-1 1-2 2-3 3-5 Ave.	2.06 4.95 4.61 5.10 4.18	25.....	0-1 1-2 2-3 3-5 Ave.	 3.23 3.65 4.18 3.69
4.....	0-1 1-2 2-3 3-5 Ave.	4.99 10.45 7.58 8.86 7.97	15.....	0-1 1-2 2-3 3-5 Ave.	1.97 3.36 4.33 5.10 3.69	26.....	0-1 1-2 2-3 3-5 Ave.	2.03 3.45 3.37 4.05 3.22
5.....	0-1 1-2 2-3 3-5 Ave.	7.31 8.40 6.49 7.10 7.32	16.....	0-1 1-2 2-3 3-5 Ave.	2.04 4.83 4.00 4.86 3.93	27.....	0-1 1-2 2-3 3-5 Ave.	4.50 4.56 4.61 4.74 4.60
6.....	0-1 1-2 2-3 3-5 Ave.	7.29 6.97 7.35 6.34 6.99	17.....	0-1 1-2 2-3 3-5 Ave.	5.58 3.75 4.88 5.00 4.80	28.....	0-1 1-2 2-3 3-5 Ave.	4.47 3.96 5.06 4.50
7.....	0-1 1-2 2-3 3-5 Ave.	6.49 7.21 5.69 6.27 6.41	18.....	0-1 1-2 2-3 3-5 Ave.	2.14 2.62 2.64 2.92 2.58	29.....	0-1 1-2 2-3 3-5 Ave.	5.50 3.61 4.30 5.24 4.66
8.....	0-1 1-2 2-3 3-5 Ave.	3.92 7.19 5.91 6.11 5.78	19.....	0-1 1-2 2-3 3-5 Ave.	1.03 2.06 2.58 3.51 2.29	30.....	0-1 1-2 2-3 3-5 Ave.	5.19 4.77 4.18 5.05 4.80
9.....	0-1 1-2 2-3 3-5 Ave.	2.88 5.10 5.37 6.02 4.84	20.....	0-1 1-2 2-3 3-5 Ave.	1.33 2.32 2.55 3.61 2.50	31.....	0-1 1-2 2-3 3-5 Ave.	5.54 5.94 4.88 5.10 5.36
10.....	0-1 1-2 2-3 3-5 Ave.	2.34 5.12 5.92 4.46	21.....	0-1 1-2 2-3 3-5 Ave.	1.06 2.81 1.89 3.75 2.38	32.....	0-1 1-2 2-3 3-5 Ave.	6.84 6.70 5.34 5.00 5.97
11.....	0-1 1-2 2-3 3-5 Ave.	2.62 4.88 5.06 5.37 4.48	22.....	0-1 1-2 2-3 3-5 Ave.	3.17 4.54 3.15 3.18 3.51			

TABLE 23
CONDUCTIVITIES OF SATURATED EXTRACTS OF SAMPLES
COLLECTED SEPT. 1958

Sample No.	Depth (ft.)	mmhos/cm	Sample No.	Depth (ft.)	mmhos/cm	Sample No.	Depth (ft.)	mmhos/cm
S1.....	0-1	7.69	S9.....	0-1	....	S17.....	0-1	6.54
	1-2	6.53		1-2	3.19		1-2	5.81
	2-3	6.04		2-3	4.54		2-3	4.15
	3-4	6.68		3-4	4.47		3-4	4.91
	Ave.	6.73		Ave.	4.07		Ave.	5.35
S2.....	0-1	12.75	S10.....	0-1	1.25	S18.....	0-1	2.00
		11.59		1-2	2.83		1-2	2.09
	1-2	8.46		2-3	4.21		2-3	1.96
	2-3	6.45		3-4	3.95		3-4	1.84
	3-4	5.66		Ave.	3.06		Ave.	1.97
	Ave.	8.98	S11.....	0-1	1.32	S19.....	0-1	1.01
S3.....	0-1	3.16		1-2	3.14		1-2	1.25
	1-2	4.53		2-3	3.73		2-3	1.76
	2-3	3.36		3-4	4.85		3-4	1.69
	3-4	4.76		Ave.	3.26		Ave.	1.43
	Ave.	3.95	S12.....	0-1	5.88	S20.....	0-1	0.85
S4.....	0-1	3.91		1-2	4.13		1-2	1.11
	1-2	5.76		2-3	4.51		2-3	1.59
	2-3	5.20		3-4	5.26		3-4	1.99
	3-4	5.00		Ave.	4.94		Ave.	1.38
	Ave.	4.97	S13.....	0-1	2.02	S21.....	0-1	0.874
S5.....	0-1	3.38		1-2	3.51		1-2	1.00
	1-2	4.38		2-3	5.00		2-3	1.59
	2-3	4.53			4.49		3-4	2.01
	3-4	5.43		3-4	4.40		Ave.	1.37
	Ave.	4.43		Ave.	3.88	S22.....	0-1	1.62
S6.....	0-1	4.76	S14.....	0-1	0.97		1-2	1.91
	1-2	6.25		1-2	2.56		2-3	1.44
	2-3	5.10		2-3	3.31		3-4	2.36
	3-4	5.27		3-4	4.88		Ave.	1.83
	Ave.	5.34		Ave.	2.93	S23.....	0-1	0.836
S7.....	0-1	3.52	S15.....	0-1	1.18		1-2	0.99
	1-2	4.07		1-2	2.41		2-3	1.85
	2-3	5.21		2-3	3.10		3-4	2.33
	3-4	5.42		3-4	3.35		Ave.	1.50
	Ave.	4.55		Ave.	2.51	S24.....	0-1	3.19
S8.....	0-1	1.52	S16.....	0-1	1.87		1-2	3.06
	1-2	4.54		1-2	4.40		2-3	2.46
	2-3	4.70		2-3	4.04		3-4	2.39
	3-4	4.88		3-4	4.60		Ave.	2.77
	Ave.	4.55		Ave.	3.73			

TABLE 23—(continued)

Sample No.	Depth (ft.)	mmhos/cm	Sample No.	Depth (ft.)	mmhos/cm	Sample No.	Depth (ft.)	mmhos/cm
S25.....	0-1	3.65	S28.....	0-1	4.55	S31.....	0-1	5.72
	1-2	2.24		1-2	5.10		1-2	3.86
	2-3	2.20		2-3	3.58		2-3	4.00
	3-4	2.56		3-4	3.61		3-4	3.21
	Ave.	2.66		Ave.	4.21		Ave.	4.20
S26.....	0-1	1.48	S29.....	0-1	1.28	S32.....	0-1	6.99
	1-2	1.27		1-2	3.57		1-2	5.02
	2-3	2.12		2-3	3.20		2-3	3.29
	3-4	3.10		3-4	3.40		3-4	3.42
	Ave.	1.99		Ave.	2.86		Ave.	4.68
S27.....	0-1	3.43	S30.....	0-1	0.896			
	1-2	4.23		1-2	1.00			
	2-3	2.98		2-3	1.87			
	3-4	.....		3-4	3.32			
	Ave.	3.55		Ave.	1.77			

page 36) ; and side losses of water, particularly south of line A which was flowing full and under pressure.

Salinity distribution. Tables 22 and 23 list the conductivity values for saturated extracts of samples obtained in March and in September 1958. The value for each depth at each site is listed to show the distribution throughout the profile. Table 24 gives the average salinity at each site on each sampling date for the test plots. These results have been used

to construct maps showing lines of equal salt concentration for March and September 1958 and April 1959.

The distribution of salinity throughout the profile in March 1958 from table 22 shows that the salinity distribution is rather uniform throughout the profile. This is to be expected since the winter water table is probably within 1 foot of the surface and little leaching below 1 foot occurs as a result of winter rainfall.

The distribution at the end of leaching

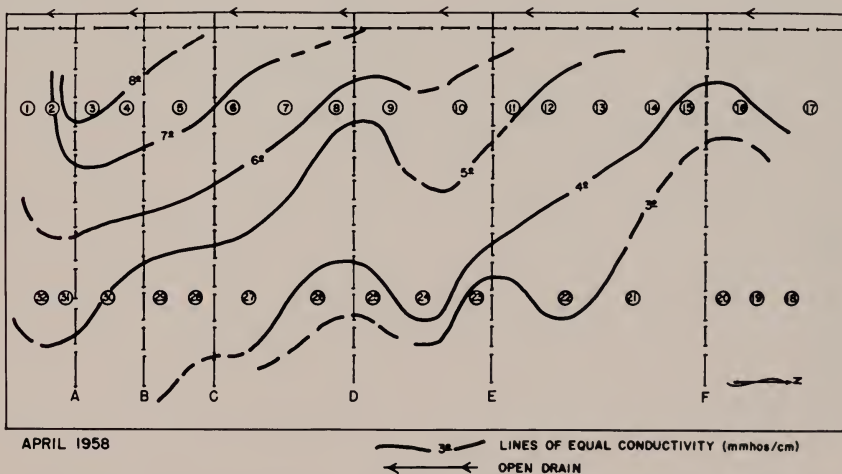


Figure 21. Lines of equal average conductivity of saturation extracts for test plot, April 1958.

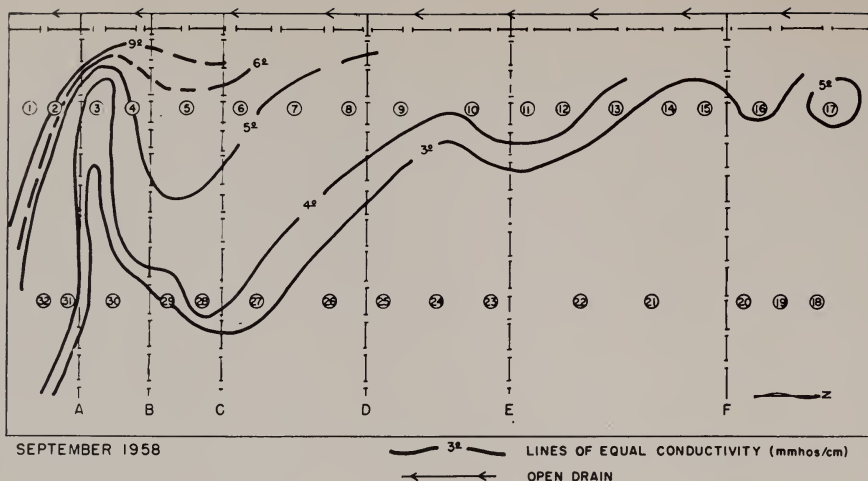


Figure 22. Lines of equal average conductivity of saturation extracts for test plot, September 1958.

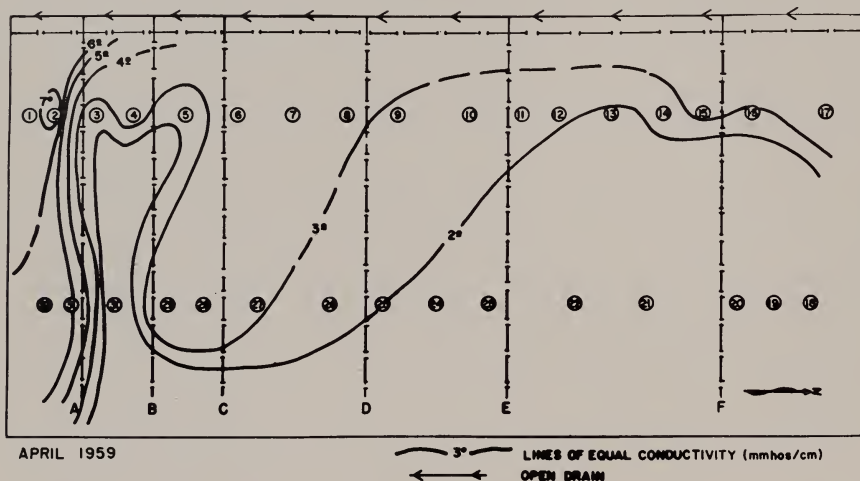


Figure 23. Lines of equal average conductivity of saturation extracts for test plot, April 1959.

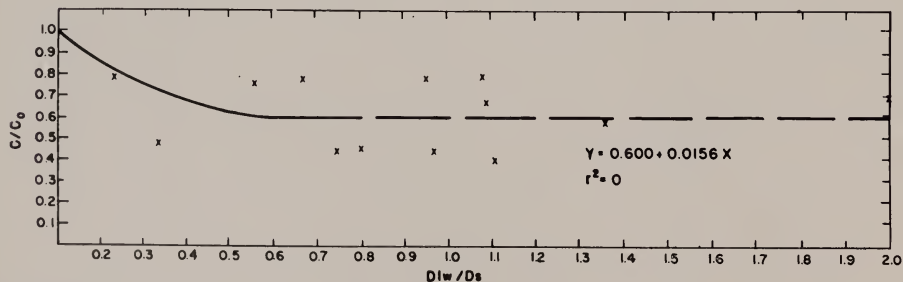


Figure 24. Depth of water per unit depth of soil required to leach Tulelake lease land soils.

period in September shows that the salinity was reduced below the March values throughout the profile. This is also shown in table 25 where the ratios of average final to initial salt expressed as concentrations are listed for each plot. The high C/C_0 value for plot 1 existed because no leaching was given in this plot. The results of this table are discussed in greater detail below.

The average salinity distribution throughout the entire 78-acre field in March and September 1958 is shown as lines of equal salt concentration in figures 21 and 22. The figure for March indicates that prior to leaching, salinity increased in a northeast to southwest direction. The largest concentration appeared in the southwest corner. If the 4 mmhos per cm contour is selected as the boundary between saline and non-saline areas, it is seen that more than half the field contained a saline condition.

The September salinity map shows that the salt contours have decreased in a northeast-southwest direction as a result of leaching and have been compressed into the southwest corner. The 4 mmhos per cm boundary has also been shifted and at this time less than half the area may be considered as saline.

Effectiveness of leaching. The average conductivity values for each plot were calculated from table 24 and the concentration values estimated from figure 5; the results are tabulated in table 25. The C_0 values refer to salinity found in the March 1958 samples, the C_1 values to midseason samples, and the C_2 values to September 1958. Table 25 also lists the C/C_0 ratio and the depth of leaching water to depth of soil (Dlw/D_s) ratio corresponding to the C_1 and C_2 values. Using these results a graph of C/C_0 vs Dlw/D_s was constructed and given in figure 24.

Figure 24 indicates that salinity is reduced fairly rapidly until a C/C_0 value of 0.6 is reached. Beyond this point the

TABLE 24

SUMMARY OF AVERAGE CONDUCTIVITIES AND CONCENTRATIONS OF SATURATED SOIL EXTRACTS FOR TEST PLOTS—MARCH, JULY, AND SEPTEMBER, 1958

Plot No.	Sampling date	Average mmhos/cm	Average meq/l
1	March.....	6.54	97.8
	July.....	6.51	97.2
	September.....	6.15	91.4
2	March.....	7.29	110.6
	July.....	5.49	80.4
	September.....	3.31	45.0
3	March.....	5.49	80.7
	July.....	6.16	91.5
	September.....	4.07	56.1
4A	March.....	6.00	88.93
	July.....	4.84	70.0
	September.....	4.66	66.9
4B	March.....	4.50	64.4
	September.....	1.12	50.6
5A	March.....	4.39	62.3
	July.....	4.49	64.2
	September.....	3.53	48.5
5B	March.....	3.59	49.4
	September.....	2.28	28.6
6A	March.....	4.64	67.0
	September.....	3.28	44.7
6B	March.....	3.51	48.4
	September.....	1.83	21.3
6C	March.....	3.27	44.6
	September.....	2.62	34.6
6D	March.....	4.18	58.9
	September.....	2.16	26.7
6E	March.....	3.69	50.9
	September.....	1.86	22.3
7A	March.....	2.50	31.4
	September.....	1.38	15.2
7B	March.....	3.11	41.5
	September.....	1.43	15.7
7C	March.....	2.58	32.9
	September.....	1.97	23.2
7D	March.....	4.80	69.0
	September.....	5.35	78.0

TABLE 25
DETERMINATION OF C/C₀ AND D_{lw}/D_s RATIOS

Plot	C ₀ * meq/C	C ₁ * meq/l	C ₁ /C ₀	D _{lw} (acre-ft.)	Plot area (acres)	Soil depth (ft.)	D _s (acre-ft.)	D _{lw} /D _s
1.....	97.8	97.2	0.994	0	....	4	....	....
2.....	110.6	80.4	0.727	0	6.05	4	24.2	....
3.....	80.7	91.5	1.134	12.019	6.15	4	24.6	0.488
4A.....	88.9	70.0	0.787	5.964	6.46	4	25.8	0.231
4B.....	64.4	....	....	8.234	5.44	4	21.8	0.378
5A.....	62.3	64.2	1.030	7.200	7.30	4	29.2	0.246
Plot	C ₀ * meq/C	C ₂ * meq/l	C ₁ /C ₀	D _{lw} (acre-ft.)	Plot area (acres)	Soil depth (ft.)	D _s (acre-ft.)	D _{lw} /D _s
1.....	97.8	91.4	0.934	....	....	4	....	....
2.....	110.6	45.0	0.407	26.610	6.05	4	24.2	1.100
3.....	80.7	56.1	0.695	49.172	6.15	4	24.6	1.999
4A.....	88.9	66.9	0.752	14.304	6.46	4	25.8	0.554
4B.....	64.4	50.6	0.786	23.390	5.44	4	21.8	1.073
5A.....	62.3	48.5	0.778	27.587	7.30	4	29.2	0.945
5B.....	49.4	28.6	0.579	25.100	4.65	4	18.6	1.349
6A.....	67.0	44.7	0.667	23.390	5.42	4	21.7	1.078
6B.....	48.4	21.3	0.440	7.837	2.64	4	10.56	0.742
6C.....	44.6	34.6	0.777	9.742	3.67	4	14.68	0.664
6D.....	58.9	26.7	0.453	9.383	2.96	4	11.84	0.794
6E.....	50.9	22.3	0.438	11.364	2.96	4	11.84	0.960
7A.....	31.4	15.2	0.484	3.074	2.34	4	9.36	0.328
7B.....	41.5	15.7	0.378	....	....	..	....	....
7C.....	32.9	23.2	0.705	....	....	..	....	....
7D.....	69.0	78.0	1.130	....	....	..	....	....

* C₀ = March samples.
C₁ = Midseason samples.
C₂ = End-season samples.

TABLE 26
CONDUCTIVITY OF SATURATED SOIL EXTRACTS—SPRING 1959

Sample	Number in sample	mmhos/cm	Sample	Number in sample	mmhos/cm	Sample	Number in sample	mmhos/cm
1	0-6.....	4.76	3	0-6.....	1.66	5	0-6.....	1.03
	6-1.....	5.82		6-1.....	1.79		6-1.....	3.40
	1-2.....	5.69		1-2.....	3.72		1-2.....	0.955
	2-3.....	5.75		2-3.....	4.07		2-3.....	1.36
	Average.....	5.50		Average.....	2.81		Average.....	1.70
	meq/l.....	80.5		meq/l.....	36.7		meq/l.....	19.5
2	0-6.....	9.50	4	0-6.....	1.28	6	0-6.....	1.22
	6-1.....	8.10		6-1.....	1.49		6-1.....	1.17
	1-2.....	6.60		1-2.....	2.77		1-2.....	0.975
	2-3.....	5.92		2-3.....	3.31		2-3.....	1.40
	Average.....	7.53		Average.....	2.21		Average.....	1.19
	meq/l.....	114.0		meq/l.....	26.7		meq/l.....	12.7

TABLE 26—(continued)

Sample	Number in sample	mmhos/cm	Sample	Number in sample	mmhos/cm	Sample	Number in sample	mmhos/cm
7	0-6.....	1.00	16	0-6.....	1.22	25	0-6.....	1.15
	6-1.....	3.41		6-1.....	1.65		6-1.....	1.11
	1-2.....	1.33		1-2.....	3.37		1-2.....	1.27
	2-3.....	3.55		2-3.....	3.92		2-3.....	1.59
	Average.....	2.32		Average.....	2.54		Average.....	1.28
	meq/1.....	28.5		meq/1.....	32.0		meq/1.....	18.0
8	0-6.....	3.29	17	0-6.....	1.46	26	0-6.....	1.22
	6-1.....	2.15		6-1.....	1.38		6-1.....	1.01
	1-2.....	4.65		1-2.....	2.07		1-2.....	0.965
	2-3.....	4.63		2-3.....	2.76		2-3.....	1.37
	Average.....	3.67		Average.....	1.92		Average.....	1.14
	meq/1.....	50.8		meq/1.....	22.5		meq/1.....	12.1
9	0-6.....	1.18	18	0-6.....	1.38	27	0-6.....	1.21
	6-1.....	1.25		6-1.....	1.71		6-1.....	1.13
	1-2.....	3.47		1-2.....	3.13		1-2.....	1.59
	2-3.....	2.43		2-3.....	2.55		2-3.....	1.81
	Average.....	2.08		Average.....	2.19		Average.....	1.44
	meq/1.....	24.8		meq/1.....	26.3		meq/1.....	15.7
10	0-6.....	4.20	19	0-6.....	1.98	28	0-6.....	1.38
	6-1.....	3.70		6-1.....	4.00		6-1.....	1.54
	1-2.....	2.42		1-2.....	5.06		1-2.....	1.56
	2-3.....	4.03		2-3.....	3.31		2-3.....	2.19
	Average.....	3.59		Average.....	3.59		Average.....	1.68
	meq/1.....	49.4		meq/1.....	49.4		meq/1.....	19.2
11	0-6.....	3.34	20	0-6.....	1.51	29	0-6.....	0.930
	6-1.....	1.79		6-1.....	1.41		6-1.....	1.86
	1-2.....	4.73		1-2.....	3.13		1-2.....	3.08
	2-3.....	4.65		2-3.....	2.42		2-3.....	2.11
	Average.....	3.63		Average.....	2.12		Average.....	2.00
	meq/1.....	50.0		meq/1.....	25.4		meq/1.....	23.5
12	0-6.....	1.22	21	0-6.....	2.83	30	0-6.....	1.05
	6-1.....	4.49		6-1.....	3.54		6-1.....	2.86
	1-2.....	3.01		1-2.....	4.07		1-2.....	3.46
	2-3.....	4.03		2-3.....	2.57		2-3.....	2.54
	Average.....	3.19		Average.....	3.25		Average.....	2.48
	meq/1.....	42.8		meq/1.....	43.6		meq/1.....	31.1
13	0-6.....	1.34	22	0-6.....	1.54	31	0-6.....	2.40
	6-1.....	1.70		6-1.....	2.09		6-1.....	3.62
	1-2.....	2.80		1-2.....	2.29		1-2.....	4.21
	2-3.....	3.36		2-3.....	1.88		2-3.....	2.87
	Average.....	2.30		Average.....	1.95		Average.....	3.28
	meq/1.....	27.0		meq/1.....	22.9		meq/1.....	49.3
14	0-6.....	3.32	23	0-6.....	2.13	32	0-6.....	6.65
	6-1.....	4.07		6-1.....	1.38		6-1.....	6.17
	1-2.....	4.77		1-2.....	1.94		1-2.....	5.32
	2-3.....	3.28		2-3.....	1.90		2-3.....	4.25
	Average.....	3.86		Average.....	1.84		Average.....	5.59
	meq/1.....	53.9		meq/1.....	22.6		meq/1.....	82.2
15	0-6.....	3.38	24	0-6.....	7.48			
	6-1.....	3.92		6-1.....	5.91			
	1-2.....	3.87		1-2.....	5.11			
	2-3.....	2.46		2-3.....	3.65			
	Average.....	3.41		Average.....	5.54			
	meq/1.....	41.5		meq/1.....	81.3			

curve flattens out to a straight line. Applying linear regression to this line the equation $Y = 0.600 + 0.0156X$ was calculated. It was found, upon further analysis, that the regression coefficient, 0.0156, was not significantly different from zero at the 1 per cent level. That is, beyond a C/C_0 value of 0.600 and Dlw/Ds value of about 0.5 the equation $Y = 0.600$ is valid showing that Y is no longer a function of X . This means that salinity is not statistically reduced (at least within the confines of the sampling location) with addition of quantities of leaching water greater than about 0.5 feet per foot depth of soil.

The statistical analysis used here should not be interpreted to mean that no additional removal of salts occurs with further leaching. Rather it is presented to indicate that these soils differ markedly in their leaching characteristics from mineral soils. A much more complete sampling of the test area would probably have indicated some additional salt removal with the large quantities of water applied. However, the efficiency of salt removal per unit depth of water moving through the profile is much lower than for other soils. These results seem to correlate well with the extremely high water transmission rates of this soil, as well as the salinity data obtained from tile outflow.

The nature of the soil structure appears to be the reason for the high flow rates and poor leaching. It will be recalled that the structure of the lease soils is such that large cracks are present between adjacent soil blocks and that these cracks provide the main avenues for water and salt transmission. During leaching, therefore, water passes rapidly through the cracks to the tile lines and much more slowly through the soil blocks. As a result, the main soil body is not effectively leached and salt diffusion from the interior of the blocks to the cracks is too slow to result in an efficient leaching. It would appear that the differ-

ential flow rate of water through this soil results in hydrodynamic dispersion during miscible displacement on a much more exaggerated scale than occurs in normal soils (Nielsen and Biggar, 1961).

Continuous flooding would represent no improvement in the leaching efficiency. If the tile lines were purposely plugged so that the water table could be raised with a minimum of water removed, some benefits from diffusion might be obtained with time.

An alternative to the flooding procedure which would provide much greater efficiencies would be the application of the leaching water to the soil surface at a rate comparable to flow through the soil blocks. This would reduce, to a minimum, water movement through the large cracks resulting in more efficient leaching of the soil blocks.

Effect of leaching by rainfall. It is believed that the leaching by rainfall obtained from September 1958 to April 1959 may have been successful because of the effect mentioned above. A comparison of the samplings in September 1958 and April 1959 indicates (see tables 23 and 26 and figures 22 and 23) considerable benefit with a small amount of water applied. The total rainfall between samplings amounted to 4.01 inches during several rainfall periods. Since it is doubtful that water became ponded on the surface, much of the rainfall probably was transmitted through the soil blocks rather than the cracks. The leaching of a soil in the unsaturated state would seem to agree with these findings (Nielsen and Biggar, 1961).

Irrigation water and tile effluent analysis. Since much of the salt found in irrigated areas is deposited in the soil from the irrigation water, it is useful to know the quality of the irrigation water. The irrigation water in the lease lands varies somewhat over the season because it is mixed from the various sources. For the lease under investigation the irrigation water was quite uniform during the

TABLE 27
ANALYSIS OF WATER FROM TILE LINES TAKEN IN JUNE AND
SEPTEMBER 1958

	Tile	Milliequivalents per liter								
		Na	Ca	Mg	K	Total	HCO ₃	Cl	SO ₄	Total
1	A	36.18	28.00	21.66	0.67	86.51	7.08	9.30	68.68	85.06
2		21.65	18.70	10.58	0.82	51.75	6.62	3.66	40.64	50.94
1	B	30.78	23.20	18.66	0.67	73.31	7.00	6.48	57.18	70.66
2		24.61	21.60	13.58	1.02	60.81	7.19	3.29	49.55	60.11
1	C	36.18	28.00	22.66	1.02	87.86	8.45	8.79	70.00	87.24
2		23.91	18.37	14.58	0.82	57.68	7.65	3.04	46.33	57.12
1	D	22.17	20.60	16.17	0.51	59.45	4.91	3.10	49.62	57.63
2		19.35	19.20	11.00	0.82	50.37	6.51	2.31	40.75	49.71
1	E	21.74	21.10	16.17	0.67	59.68	5.94	3.27	48.76	57.97
2		18.78	18.70	9.67	0.82	47.97	7.54	2.03	37.63	47.44
1	F	17.17	20.15	13.83	0.51	51.66	5.94	4.20	41.38	51.52
2		16.87	16.35	9.67	0.61	43.50	8.34	1.97	32.91	43.34

1 = Samples collected June 10, 1958.

2 = Samples collected September 16, 1958.

ANALYSIS OF IRRIGATION WATER

Milliequivalents per liter									
Na	Ca	Mg	K	T	HCO ₃	Cl	SO ₄	Total	SAR
2.07	1.12	1.84	0.16	5.19	3.54	0.39	1.26	5.19	1.73

leaching period. The analysis given in table 27 indicates that it is a medium-salt low-sodium water. The bicarbonate content is somewhat high and shows that there are 0.58 me/l of residual sodium carbonate. The presence of excessive bicarbonate is undesirable because of the low solubility of calcium carbonate. Removal of calcium from the soil solution by precipitation of the Ca with the bicarbonate increases the proportion of sodium to calcium and magnesium in the soil solution. This increase in sodium results in an increase of exchangeable sodium which over a period of time under accumulative conditions may lead to problems associated with excessive exchangeable sodium.

Tile outflow analysis. The quantity of outflow from the tile lines has been shown previously to fluctuate drastically

during the leaching tests. Several conductivity measurements during the leaching period indicate that the salinity fluctuates also but to a much lesser extent. In fact the analysis presented in table 27 of waters taken near the beginning and end of the leaching trials indicates a rather low salt load initially and a corresponding high salt load after the application of many feet of water. In general, the salt load in the tile effluent remained somewhat constant throughout the season. The low initial salt loads and more or less constant salinity throughout the season indicates that considerable dilution of the salty effluent by irrigation water has occurred. These results compare favorably with the rather poor leaching of the soil and the fact that considerable flow occurred through the cracks rather than the soil blocks.

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